NITROGEN AND POTASSIUM FERTILIZATION OF A NO-TILLAGE RYE-SOYBEAN DOUBLE-CROPPING SYSTEM

BY

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"... for dust you are
and to the dust you will return."
Genesis 3:19

To

My wife Olivieth, my son Rubén Alberto, my daughter Natalie, my father Alberto, my mother Vilma; to the memory of my grandparents: Rubén, the farmer, Guillermo, the wise, Rosalía, and Felicia. To Nelly; to my niece and my nephews; to Maruja, to the rest of my family and friends; and to the Costa Rican farmer whom I love.

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NITROGEN AND POTASSIUM FERTILIZATION OF A NO-TILLAGE RYE-SOYBEAN DOUBLE-CROPPING SYSTEM

By

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Chairman: Raymond Noel Gallaher
Major Department: Agronomy

This research was conducted to evaluate the K and N fertilizer application response in a 11-yr-old no-tillage (NT) rye (*Secale cereale* L.)-soybean [*Glycine max* (L.) Merr.] double-cropping (DC) system. The experiment was conducted in an area dominated by Grossarenic and Arenic Paleudults near Gainesville, FL. A randomized complete block design with four replications nested within cropping cycles (CC) in a modified 5X5 factorial was used with N assigned at random and K assigned at random within each N treatment. Main plots consisted of two CC (1985-1986 and 1986-1987). Sub-plots consisted of five N rates (0, 39, 78, 117, and 156 kg ha^{-1}) each containing five sub-sub-plots of K (0, 45, 90, 135, and 180 kg ha^{-1}). Soil and plant N and K were determined. The Extension Service fertilizer recommendations for monocrop rye and soybean were also tested in this experiment. Fertilizer had a positive effect on rye whole plant dry matter (WPDM), rye grain (GY), percent ground cover, head area index, head weight, percent grain head^{-1}, and soybean seed yield (SY). The application of P was not necessary to obtain greater net dollar returns from estimated sales of rye WPDM, GY, and SY. It was not necessary to apply fertilizer to the soybean crop when fertilizer was applied to the previous rye crop. No-tillage DC systems require a different fertilizer system as compared to monocropping either rye or soybean.

An interaction between N and sampling time was observed. Higher soil N concentrations were observed after the soybean crops. This indicated that N was recycled to the soil surface from plant residue decomposition immediately after the soybean growing season. The opposite effect was found after the rye crops when interactions between extractable soil K and sampling times were observed. Fertilizer N X K interactions were obtained in different rye and soybean plant parts during both the 1985-1986 and the residual CC.

Nitrogen and K nutrients were recycled from crops to soil. Researchers should consider the agro-ecological factors involved in DC practices in order to make appropriate and economical recommendations for fertilization of NT DC of rye and soybean.

CHAPTER 1

INTRODUCTION

Minimum-tillage and multiple-cropping as a method of crop production is increasingly being used in the United States and around the world. Savings in fuel, labor, and other resources such as soil, water and time are advantages claimed for using minimum-tillage and multicropping systems.

Agronomists are concerned about the long-term effect of no-tillage with double-cropping on nutrient availability, fertilization, and plant residue management along with the economic strategies for sustaining crop production. Maximum yields per land unit may not be appropriate goals if uneconomical management inputs are required. Research is needed to compare past findings in conventional-tillage and monocropping with no-tillage and double-cropping and to determine economic implications.

Rye [Secale cereale (L.)], often double-cropped with soybean [Glycine max (L.) Merr.], is grown on many hectares in Florida every year. This experiment was carried out to determine fertilizer requirements for the most profitable production of rye and soybean under a no-tillage, double-cropping system in the nutrient deficient, sandy soils typically used.

CHAPTER 2

MATERIALS AND METHODS

The experimental area was on the Agronomy Department Research Farm, 22 km west of Gainesville, Florida. The experiment site was dominated by Arenic and Grossarenic Paleudults (Soil Survey Staff, 1984). This area had been double-cropped (DC) with rye [_Secale cereale_ (L.)]-soybean [_Glycine max_ (L.) Merr.] using no-tillage (NT) methods for both crops during the previous 9 to 11 yr. The site had received no fertilizer for 6 yr before this experiment was started. Nitrogen deficiency symptoms in the rye crop were evident each year and K deficiency symptoms had been observed to varying degrees in the soybean. In November 1985 the soybean crop was removed and a N and K fertility experiment was started.

Phase I

"Wrens Abruzzi" rye was seeded at the rate of 100 kg ha^{-1} on November 20, 1985 and 1986. Following the rye crop, "Centennial" soybean was planted in mid-June 1986 and 1987 in 25 cm-wide rows using a NT "Tye" drill. Soybean was seeded at the rate of 24 seed m^{-1} of row. Standard cultural and pest management practices were carried out as required for each crop (Table 2-1).

Double-cropping of rye and soybean during November 1985 to October 1986 constituted the first cropping cycle (CC) (85-86) and from November 1986 to October 1987 constituted the second CC (86-87) (Fig. 2-1). Plots used during the 86-87 CC were adjacent to plots used during the 85-86 CC. Identical data were collected for both the 85-86 and 86-87 CC.

A randomized complete block design with four replications nested within CC in a modified 5X5 factorial with N assigned at random and K assigned at random within each N treatment was used. Main plots consisted of two CC (85-86 and 86-87). Sub-plots consisted of five N rates (0, 39, 78, 117, and 156 kg ha^{-1}) each containing five sub-sub-plots of K (0, 45, 90, 135, and 180 kg ha^{-1}). Sub-sub-plots were 3.0 by 5.0 m in size. The statistical model used was expressed by Eq. [2-1] and Table 2-2:

$$Y_{ijkl} = M + C_i + R_{j(i)} + N_k + (CN)_{ik} + e_{ijk} + K_l + (CK)_{il} + (NK)_{kl} + (CNK)_{ikl} + e_{ijkl} \qquad \text{[Eq. 2-1]}$$

Y_{ijkl} = response

M = mean

C_i = cropping-cycles i = 1,2

$R_{j(i)}$ = replications i = 1,2...4

N_k = nitrogen k = 1,2....5

K_l = potassium l = 1,2....5

e = random error

Table 2-1. Pest control practices used for rye and soybean.

Practice and product	Rate of active ingredient	Type of application	Crop	
			Rye	Soybean
	-kg ha^{-1}-			
Weed Control				
Gramoxone (paraquat)	0.60	preplant	X	X
Round-up (glyphosate)	0.60	preplant	X	X
Lasso (alaclhor)	2.20	preemergence	-	X
Lexone (metribuzin)	0.40	preemergence	-	X
Basagran (bentazon)	0.60	post-emergence direct	-	X
Insect Control				
Orthene (acephate)	0.60	broadcast	-	X
Lannate (methomyl)	0.45	broadcast	-	X
Disease Control				
Benlate (benomyl)	0.60	broadcast	-	X

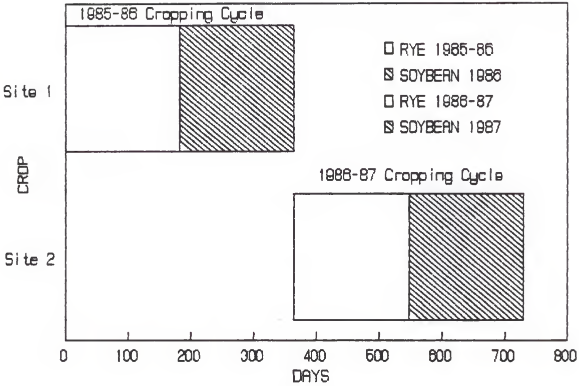

Fig. 2-1. Two-year no-tillage rye-soybean cropping cycles (using different sites for both the 1985-86 and the 1986-87 cropping cycles).

Table 2-2. Expected mean squares for a 5X5 factorial experiment

Source	d.f.	Expected Mean Squares
C_i	1	$\sigma^2 + d\,\sigma^2_{R(C)CN} + acd\,\theta^2_C$
$R(C)_{j(i)}$	6	$\sigma^2 + cd\,\sigma^2_{R(C)}$
N_k	4	$\sigma^2 + d\,\sigma^2_{R(C)CN} + abd\,\theta^2_N$
$(CXN)_{ik}$	4	$\sigma^2 + d\,\sigma^2_{R(C)CN} + bc\,\theta^2_{CN}$
Error	24	$\sigma^2 + d\,\sigma^2_{R(C)CN}$
K_l	4	$\sigma^2 + abc\,\theta^2_K$
CXK	4	$\sigma^2 + ac\,\theta^2_{CK}$
$(NXK)_{kl}$	16	$\sigma^2 + ab\,\theta^2_{NK}$
$(CXNXK)_{jkl}$	16	$\sigma^2 + a\,\theta^2_{CNK}$
Error	120	σ^2
Total	199	

Ammonium nitrate and muriate of potash were used as sources of N and K, respectively. All K applications were made at rye planting time while N was applied 1/3 at planting and 2/3 at the beginning of February. Fertilizer was applied only to the rye crop in a cycle.

A 0.5 m by 3.0 m (1.5 m^2) quadrant from the center of each plot was used to collect samples for evaluating rye whole plant dry matter (WPDM), rye grain yield (GY1), rye percent ground cover (GC), and yield of soybean grain (SY). A 1 m by 0.25 m (0.25 m^2) quadrant was also used to evaluate grain yield (GY2), head weight (HW), percent grain $head^{-1}$ (PGH), and head area index (HAI) of the rye. Testing of differences among treatments was made by the Fisher Protected Least Significant Difference Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). When ANOVA indicated a significant ($P < 0.05$) treatment effect, regression was used for comparing treatment means.

Phase II

Plots used during the 85-86 CC were planted and sampled the second year (residual (R) CC) in order to evaluate the 2-yr long-term residual effect of previously applied K fertilizer. Only yield data were collected. A randomized complete block design with four replications in a modified 5X5 factorial was used with N assigned at random and K assigned at random within each N treatment. Main plots consisted of two CC (85-86 and R) (Fig. 2-2). Sub-plots consisted of five N rates (0, 39, 78, 117, and 156 kg ha^{-1}) each containing five sub-sub-plots of K (0, 45, 90, 135, and 180 kg ha^{-1}). Sub-sub-plots were 3.0 by 5.0 m in size. Nitrogen was applied to the rye crop on both the 85-86 CC and the R CC. Potassium was applied to the rye crop only during the 85-86 CC. Testing of differences among treatments was made as described in phase I. The statistical model used was expressed by Eq. [2-2] and Table 2-3:

$$Y_{ijkl} = M + R_i + C_j + N_k + (CN)_{jk} + e_{ijk} + K_l + (CK)_{jl} + (NK)_{kl} + (CNK)_{jkl} + e_{ijkl} \qquad \text{Eq.[2-2]}$$

Y_{ijkl} = response

M = mean

R = replications i = 1,2...4

C_j = cropping cycle j = 1,2

N_k = nitrogen k = 1,2....5

K_l = potassium l = 1,2....5

e = random error

Phase III

Another experiment tested some specific fertilizer treatments that included the current extension recommendation of N and K for small grain (78 kg N ha^{-1}, 9 kg P_2O_5 and 90 kg K_2O ha^{-1}), and K for soybean (90 kg K_2O ha^{-1}). These recommendations were given by the Institute of Food and Agricultural Sciences Extension Soil Testing Laboratory.

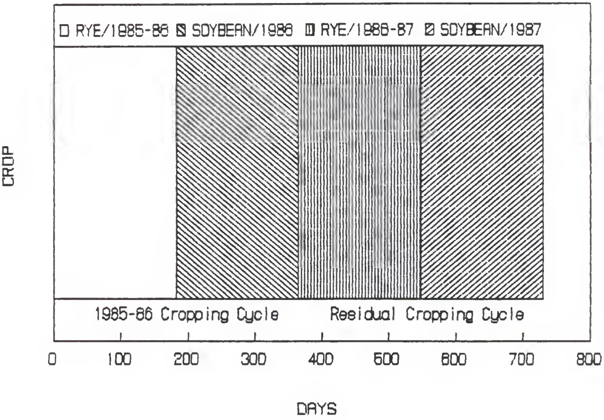

Fig. 2-2. Long-term no-tillage rye-soybean cropping cycles (using the same site for both the 1985-86 and the residual cropping cycles).

Table 2-3. Expected mean squares for a 5X5 factorial experiment

Source	d.f.	Expected Mean Squares
R_i	3	$\sigma^2 + bcd\ \sigma^2_R$
C_j	1	$\sigma^2 + cd\ \sigma^2_{RC} + acd\ \theta^2_C$
Error	3	$\sigma^2 + cd\ \sigma^2_{RC}$
N_k	4	$\sigma^2 + d\ \sigma^2 RCN + abd\ \theta^2_N$
$(CXN)_{jk}$	4	$\sigma^2 + d\ \sigma^2_{RCN} + ad\ \theta^2_{CN}$
Error	24	$\sigma^2 + d\ \sigma^2_{RCN}$
K_l	4	$\sigma^2 + abc\ \theta^2_K$
$(CXK)_{jl}$	4	$\sigma^2 + ac\ \theta^2_{CK}$
$(NXK)_{kl}$	16	$\sigma^2 + ab\ \theta^2_{NK}$
$(CXNXK)_{jkl}$	16	$\sigma^2 + a\ \theta^2_{CNK}$
Error	120	σ^2
Total	199	

The fertilizer treatments for this experiment were the following: (1) 78-9-90 kg ha^{-1} (extension service recommendation of N-P-K for the rye crop), (2) 78-0-90 (rye crop recommendation of N and K but minus the P), (3) monocrop fertilizer recommendation for rye (78-9-90) and soybean (0-0-90) applied to each crop during both the 85-86 and 86-87 CC of the experiment, and (4) the best response obtained for either WPDM or RG1 from the factorial analysis of phase I, 117-0-135 for rye WPDM and 117-0-180 for RG1, respectively. The design was a randomized complete block with four replications. Testing of differences among treatments was made by the Fisher Protected Least Significant Difference Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). Economical analyses of the data were conducted using the current fertilizer and crop prices (R.N. Gallaher, 1987, personal communications).

Phase IV

Similar procedures used for phase III was followed in this phase. However, this phase dealt with the long-term effect of repeated application of fertilizer on the same plots during both the 85-86 CC and the R CC. The fertilizer treatments for this experiment were the following: (1) 78-9-90 kg ha^{-1} (extension service recommendation of N-P-K for the rye crop), (2) 78-0-90 (rye crop recommendation of N and K but minus the P), (3) monocrop fertilizer recommendation for rye (78-9-90) and soybean (0-0-90) applied to each crop during the 85-86 CC, (4) recommended fertilizer for rye (78-0-90) and soybean (0-0-90) applied to each of the crops during both 85-86 CC and R CC of the experiment, and (5) the best response obtained for either WPDM or RG1 from the factorial analysis of phase I (180-0-135 for WPDM and 117-0-180 for RG1). The design was a randomized complete block with four replications. Testing of differences between treatments was as described in phase III.

Phase V

Before initial application of treatments described in phase II, soil samples were collected from the 0.00 to 0.05, 0.05 to 0.10, 0.10 to 0.15, 0.15 to 0.30, 0.30 to 0.45, and 0.45 to 0.60 m depths for analysis of soil N and extractable K. Soil samples were also taken to a depth of 0.60 m in November 1985, 1986, and 1987 immediately after the soybean crop and to a depth of 0.30 m in May 1986 and 1987 immediately after the rye crop (Table 2-4). Samples were air dried and sieved to pass a 0.002 m stainless steel screen.

Rye tissue samples were collected at tillering and early bloom stages in 1986 and 1987. Soybean tissue samples were collected at R2 stage (full bloom) (Fehr and Caviness, 1977) in 1986 and 1987. Samples of rye grain and soybean seed were collected at harvest time in 1986 and 1987. Samples were dried at 70 C in a forced-air oven, ground using a Wiley mill, and analyzed for N and K.

Table 2-4. Soil sampling procedure.

Date of sampling	Time after begining of the experiment	Depth of sampling	Previous crop
	-days-	---m---	
November 1985	0	0.60	soybean
May 1986	183	0.30	rye
November 1986	365	0.60	soybean
May 1987	548	0.30	rye
November 1987	730	0.60	soybean

Soil and plant N was analyzed by using a Kjeldahl digestion (Gallaher et al., 1975; Gallaher et al., 1976) followed by colorimetric determination by a Technicon II AutoAnalyzer. Soil K was determined by double acid (Mehlich I) extraction (Mehlich, 1953) followed by flame emission spectrophotometry. Plant K was determined by dry ashing, acid extraction and flame emission spectrophotometry (Jones and Steyn, 1983). Testing of differences among treatments was made by the Fisher Protected Least Significant Difference Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). When ANOVA indicated a significant ($P < 0.05$) treatment effect, regression was used for comparing treatment means of plant variables.

CHAPTER 3
YIELD RESPONSE OF A NO-TILLAGE RYE-SOYBEAN DOUBLE-CROPPING SYSTEM AFFECTED BY NITROGEN AND POTASSIUM FERTILIZATION

Introduction

Small grain followed by soybeans [Glycine max (L.) Merr.] is the agronomic double-cropping (DC) system most widely grown in the United States and probably in the world. Wheat [Triticum aestivum (L.) em Thell] following by soybean is probably the most common DC system practiced in the United States. Tillage and related management practices for this DC system have been evaluated by numerous researchers (Gallaher, 1977a, Gallaher, 1977b; Gallaher and Weaver, 1982; Hargrove et al., 1982; Sanford, 1982; Touchton and Johnson, 1982; NeSmith et al., 1987; Sharpe et al., 1988). A larger variety of small grain-soybean DC systems [soybean followed by rye (Secale cereale L.) grain (Westberry and Gallaher, 1979), wheat after soybean or dormant summer perennial grasses (Wright, 1984), soybean or grain sorghum [Sorghum bicolor (L.) Moench.] followed by oat (Avena sativa L.) (Ortiz and Gallaher, 1984; Ortiz, 1985), and others suggested by Gallaher et al. (1980)] can be practiced in the prevailing warm climate of Florida. Therefore, the soil fertility management of DC systems is important.

Hargrove et al. (1983) indicated that wheat growth, N status, and grain yield are influenced by the previous crop and are important to the management of DC systems. Gallaher (1977a) mentioned that "in general the DC systems were fertilized with less N and about equal or slightly more P and K than the sum of what would be recommended for the winter and summer crops if grown separately as monocrops" (p. 6). Post (1983) indicated that soybean appeared to leave sufficient N to meet the needs of rye in a no-tillage (NT) rye-soybean DC system. However, insufficient soil K may be a problem when such DC is practiced. This study was conducted to evaluate the N and K fertilizer response in a 11-yr-old NT rye-soybean DC system.

Materials and Methods

"Wrens Abruzzi" rye was seeded at the rate of 100 kg ha^{-1} on November 20, 1985, and 1986. Following the rye crop, "Centennial" soybean was planted in mid-June 1986 and 1987 in 25 cm-wide rows using a NT "Tye" drill. Soybean was seeded at the rate of 24 seed m^{-1} of row. Standard cultural and pest management practices were carried out as required for each crop (Table 2-1).

Double-cropping of rye and soybean during November 1985 to October 1986 constituted the first cropping cycle (CC) (85-86) and from November 1986 to October 1987 constituted the second CC (86-87) (Fig. 2-1). Plots used during the 86-87 CC were adjacent to plots used during the 85-86 CC.

Identical data were collected for both the 85-86 and 86-87 CC.

A randomized complete block design with four replications nested within CC in a modified 5X5 factorial with N assigned at random and K assigned at random within each N treatment was used. Main plots consisted of two CC (85-86 and 86-87). Sub-plots consisted of five N rates (0, 39, 78, 117, and 156 kg ha^{-1}) each containing five sub-sub-plots of K (0, 45, 90, 135, and 180 kg ha^{-1}). Sub-sub-plots were 3.0 by 5.0 m in size. The statistical model used was expressed by Eq. [2-1] and Table 2-2:

$$Y_{ijkl} = M + C_i + R_{j(i)} + N_k + (CN)_{ik} + e_{ijk} + K_l + (CK)_{il} + (NK)_{kl} + (CNK)_{ikl} + e_{ijkl} \qquad \text{[Eq. 2-1]}$$

Y_{ijkl} = response

M = mean

C_i = cropping-cycles $i = 1,2$

$R_{j(i)}$ = replications $i = 1,2...4$

N_k = nitrogen $k = 1,2....5$

K_l = potassium $l = 1,2....5$

e_{ijkl} = random error

Ammonium nitrate and muriate of potash were used as sources of N and K, respectively. All K applications were made at rye planting time while N was applied 1/3 at planting and 2/3 at the beginning of February. Fertilizer was applied only to the rye crop in a cycle.

A 0.5 m by 3.0 m (1.5 m^2) quadrant from the center of each plot was used to collect samples for evaluating rye whole plant dry matter (WPDM), rye grain yield (GY1), percent ground cover of rye (GC), and yield of soybean grain (SY). A 1 m by 0.25 m (0.25 m^2) quadrant was also used to evaluate grain yield (GY2), head weight (HW), percent grain $head^{-1}$ (PGH), and head area index (HAI) of the rye.

Testing of differences among treatments was made by the Fisher Protected Least Significant Difference Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). When ANOVA indicated a significant ($P < 0.05$) treatment effect, regression was used for comparing treatment means. The following model was used to show the curvilinear response to N and the linear response to K when multiple regression techniques were used (Steel and Torrie, 1980):

$$Y = b_0 + b_1 N - b_2 N^2 + b_3 K \qquad [3\text{-}1]$$

In this equation, Y is the predicted value and N and K refer to coded rates of fertilizer applied. The b values are the computed regression coefficients for the intercept and the linear and quadratic effects of the applied nutrients.

Results and Discussion

No interactions occurred in this experiment. Higher variable values were found for rye GY1, GC, HW, GY2, and SY during the 85-86 CC as compared with the 86-87 CC (Table 3-1). No differences were found for HAI. Percent grain $head^{-1}$ showed higher values during the 86-87 CC. Rye WPDM, GY1, and HAI had a curvilinear response to N and a linear response to K during the 85-86, 86-87 CC and the CC average (avg).

Table 3-1. Regression coefficients for linear and quadratic equation predicting yield of rye and soybean.

Cropping cycle	Intercept	N Linear	K Linear	N Quadratic	R^2
- Rye whole plant dry matter -					
			kg ha^{-1}		
85-86	2449	4.36E+01**	4.16E+00**	-1.38E-01**	0.77
86-87	2304	4.27E+01**	5.86E+00**	-1.53E-01**	0.63
Avg	2376	4.31E+01**	5.01E+00**	-1.46E-01**	0.69
- Rye grain yield 1 (GY1) -					
			kg ha^{-1}		
85-86	293	6.96E+00**	5.68E-01*	-1.85E-02*	0.57
86-87	139	3.95E+00**	6.16E-01*	-1.81E-02*	0.17
Avg	216	5.45E+00**	5.92E-01*	-1.83E-02*	0.23
- Soybean yield -					
			kg ha^{-1}		
85-86	2535	NS	2.39E+00**	NS	0.18
86-87	1869	NS	2.86E+00**	NS	0.17
Avg	2202	NS	2.63E+00**	NS	0.15
- Rye ground cover -					
			%		
85-86	56	5.32E-01**	3.71E-02*	-1.96E-03**	0.59
86-87	56	1.64E-01**	3.32E-02*	NS	0.62
Avg	59	3.50E-01**	3.52E-02*	NS	0.45

Table 3-1--continued.

		- Rye head area index (HAI) -			
		cm^{2}m^2			
85-86	125	2.32E+00**	3.56E-01**	-6.43E-03*	0.53
86-87	141	3.44E+00**	3.23E-01**	-1.40E-02**	0.52
Avg	133	2.88E+00**	3.39E-01**	-1.02E-02**	0.51
		- Rye head weight - [a]			
		kg ha^{-1}			
85-86	517	3.06E+00**	9.54E-01**	NS	0.39
86-87	157	5.85E+00**	5.74E-01*	-2.69E-02**	0.31
Avg	337	4.45E+00**	7.64E-01*	-2.09E-02**	0.20
		- Rye grain yield (GY2) - [a]			
		kg ha^{-1}			
85-86	312	3.64E+00**	1.01E+00*	NS	0.32
86-87	216	5.55E+00**	NS	-2.60E-02**	0.13
Avg	264	4.60E+00**	7.27E-01*	-1.96E-02*	0.19

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*,** Regression coefficients for which coefficients of determination were computed were significant at the 0.05 and 0.01 probability levels respectively; NS = not significant; [a] rye head weight and rye grain yield (GY2) were obtained from a harvested area of 0.25 m^2, 1.5 m^2 harvest area was used for all the other variables.

Rye HW showed the same response for the 86-87 CC and the avg CC. However, no quadratic effect for N was observed for this variable during the 85-86 CC. The opposite response was observed for GC (Table 3-1). Soybean seed yield did not respond to the application of N on the rye crop but showed a linear response to the residual K (Table 3-1) as in Eq. [3-2].

$$Y = b_0 + b_1 K \qquad [3\text{-}2]$$

Rye GY2 responded linearly for both N and K applications during the 85-86 CC, did not respond to K, but showed a curvilinear response to N during the 86-87 CC. A curvilinear and linear response to N and K, respectively, was observed for the CC avg (Table 3-1). Rye GY2 did not follow similar trends when compared with rye GY1. Apparently, the smaller sampling area created greater variability among the GY2.

Coefficients of determination (R^2) were relatively low in this experiment (Table 3-1). This was mostly because of the variable depth of the soil clay of the experimental site and the effect of late freezings that affected the rye crop during both years of the experiment.

Highest yields of rye WPDM where obtained when 117 kg N ha^{-1} were applied (Table 3-2) during the 85-86, 86-87, and CC avg. Response to N increased linearly up to the 117 kg ha^{-1} fertilizer rate and then decreased at the highest N rate (156 kg ha^{-1}). Similar results were observed for rye

Table 3-2. Rye and soybean yield variables as affected by N and K fertilization.

Yield variable	N rate	Cropping cycle			K rate	Cropping cycle		
		85-86	86-87	Avg		85-86	86-87	Avg
Rye WPDM[a]				kg ha^{-1}				
	0	1800	2100	1950	0	3400	3200	3300
	39	3100	2900	3000	45	3900	3600	3750
	78	4300	4500	4400	90	3900	4200	4050
	117	5200	5100	5150	135	4200	4200	4200
	156	5100	4700	4900	180	4100	4200	4150
FPLSD[b]		750	1150	600		400	500	300
				kg ha^{-1}				
Rye grain	0	400	200	300	0	700	300	500
(GY1)	39	490	300	395	40	660	280	470
	78	770	370	570	90	740	380	560
	117	1010	450	730	135	740	330	535
	156	930	350	640	180	760	410	585
FPLSD		220	NS	160		110	100	70
				kg ha^{-1}				
Soybean	0	2200	1400	1800	0	1800	1400	1600
seed	39	2200	1500	1850	45	2300	1600	1950
yield	78	2100	1500	1800	90	2200	1700	1950
	117	2400	1900	2150	135	2300	1800	2050
	156	2200	2100	2150	180	2300	1900	2100
FPLSD		NS	NS	NS		400	300	250
Rye	kg ha^{-1}		%		kg ha^{-1}		%	
ground	0	47	43	45	0	45	50	58
cover	39	67	48	58	45	70	55	63
	78	75	53	64	90	71	56	64
	117	83	61	72	135	74	56	65
	156	82	68	75	180	72	57	65
FPLSD		17	11	9		6	5	4

Table 3-2--Continued

Rye head area index	kg ha^{-1}							
	0	140	140	140	0	200	210	205
	39	180	220	200	45	240	280	260
	78	260	310	285	90	270	290	280
	117	260	360	310	135	260	280	270
	156	320	310	315	180	270	290	280
FPLSD		90	80	50		60	40	30
Rye head weight[c]	kg ha^{-1}							
	0	600	320	460	0	780	320	550
	39	680	420	550	45	800	420	610
	78	840	490	660	90	900	480	690
	117	1120	550	835	135	880	440	660
	156	980	460	720	180	900	440	670
FPLSD		210	1990	140		130	NS	85
Rye grain (GY2)[c]	kg ha^{-1}							
	0	400	210	305	0	530	320	425
	39	490	410	450	45	570	410	490
	78	630	470	550	90	750	470	610
	117	1015	520	770	135	650	400	525
	156	780	450	615	180	740	430	585
FPLSD		300	NS	200		170	NS	120
Percent grain head^{-1}[c]	kg ha^{-1}	%			kg ha^{-1}	%		
	0	30	42	36	0	35	43	39
	39	29	44	37	45	29	39	34
	78	32	40	36	90	35	41	38
	117	39	39	39	135	34	38	36
	156	38	37	38	180	34	40	37
FPLSD		8	NS	NS		6	NS	NS

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[a] whole plant dry matter, [b] Fisher Protected Least Significant Difference Test (P <0.05), NS = not significant (P >0.05), [c] rye head weight, rye grain yield (GY2), and percent grain head^{-1} were obtained from a harvested area of 0.25 m^2, 1.5 m^2 harvested area was used for all other variables.

GY1, even though no differences were found for the 86-87 CC year according to the F-test ($P < 0.05$). When compared to the 0 kg K ha^{-1} rate, rye WPDM responded to K application at all rates during the 85-86, 86-87, and CC avg (Table 3-2). There was a slight trend toward higher yields of rye WPDM when higher K rates were applied. An analogous trend was observed for the response of rye GY1 to K application. In this case statistical differences were found only to the highest rate of K applied (180 kg ha^{-1}) for the 85-86, 86-87, and the CC avg, respectively (Table 3-2).

Soybean seed yield did not respond to residual N. However, a trend of greater SY was observed from increasing N rates applied to the rye crop. Soybean seed yield showed a response to the residual K at the 45 kg K ha^{-1} rate for the 85-86 and the CC avg, and to the 180 kg K ha^{-1} rate for the 86-87 CC (Table 3-2). This indicated that the K applied to the rye crop was cycled through the rye residue and returned to the soil to be used by the succeeding soybean crop. These results reinforce Post's (1983) conclusions that "in general, DC of rye followed by soybeans efficiently recycles nutrients from crop to soil" (p. viii).

Rye PGC responded significantly to the application of 39 kg N ha^{-1} for the 85-86 CC and 156 kg N ha^{-1} for the CC avg (Table 3-2). Rye PGC responded to the application of 135 kg K ha^{-1} during the 85-86 CC. A response to the application of 45 kg K ha^{-1} was observed for this variable for both the 86-87 and the CC avg. A linear increase in rye PGC in response to both N and K applications was observed for the 86-87 CC and the avg CC. A curvilinear effect in rye PGC in response to these fertilizer applications was observed for the 85-86 CC. Greater ground cover percentages could be important to protect the soil against water and wind erosion. This could be an important factor when the rye crop is grown for the dual purpose of either dry matter (pasture grazing and/or silage) or grain production and as a winter cover crop for erosion control.

Rye HAI responded to the application of 117 kg N ha^{-1} in all years and showed a linear increase in response to N for the 85-86 and avg CC (Table 3-2). Rye HAI increased linearly up to the rate of 117 kg N ha^{-1} and decreased at the highest N rate of 156 kg N ha^{-1} during the 86-87 CC. A similar response was observed for the rye HW. Rye HAI responded to the application of 90 kg K ha^{-1} during the 85-86 CC and 45 kg K ha^{-1} during the 86-87 and the CC avg, respectively (Table 3-2). Rye HW responded to the application of 90 kg K ha^{-1} during the 85-86 and to 90 kg K ha^{-1} for the CC avg (Table 3-2).

Rye GY2 showed a response to the application of 117 kg N ha^{-1} during both the 85-86 and the CC avg. Rye GY2 increased linearly up to the rate of 117 kg N ha^{-1} and decreased at the highest N rate of 156 kg N ha^{-1} (FPLSD 0.05) (Table 3-2). A similar trend was observed during the 86-87 CC. A response of rye GY2 to the application of 90 kg K ha^{-1} was observed for the 85-86 and the CC avg (FPLSD

0.05) (Table 3-2). A trend of an analogous behavior was observed during the 86-87 CC. Variability increased when the smaller sampling area was used (0.25 m^2) as compared with the larger 1.5 m^2 sampling area.

Rye PGH responded to the application of 117 kg N ha^{-1} and 90 kg K ha^{-1} during the 85-86 CC (FPLSD 0.05) (Table 3-2). The total grand mean for the rye PGH was 37 % for the CC avg. This could be used to indicate how rye heads reached only about a third of their total potential grain filling capacity. This could be explained by the early increase in temperatures and the later freezes that occurred during the spring that is usual under the Florida subtropical climate. Thus, even though the rye heads were fully developed, the rye grain filling process was disrupted by the late low temperatures.

Conclusions

Fertilizer had a positive effect on rye WPDM, rye grain yields (GY1 and GY2), rye PGC, HW, PGH, HAI, and SY in this NT DC system. Soybean seed yield responded positively to residual K which had been applied to the rye crop. Thus, when K was applied to satisfy the needs of the rye crop, no additional K was needed for the soybean crop. These results agree with those suggested by Gallaher (1977a) who felt that fertilizer applied to one crop may leave enough residual nutrients for a succeeding crop, thereby reducing costs to the total multiple-cropping system. Researchers should take the residual effects of fertilizer into account before making extension recommendations. A rye-soybean NT DC system will require different management as compared with monocropping either rye or soybean.

CHAPTER 4
LONG-TERM NITROGEN AND POTASSIUM FERTILIZATION EFFECT ON YIELD OF A NO-TILLAGE RYE-SOYBEAN DOUBLE-CROPPING SYSTEM

Introduction

Thousands of ha of rye (*Secale cereale* L.) are grown in Florida and they are often double-cropped with soybean [*Glycine max* (L.) Merr.]. Very little information is currently available about fertility management practices of no-tillage (NT) rye-soybean double-cropping (DC) systems. Nitrogen and K are two of the most important nutrients in crop nutrition. Fraiser (1983) investigated the effects of N and K on yields, net profits, crop growth, and the effects of N on soil pH in two maize (*Zea mays* L.)-soybean NT DC systems in Florida. Maize growth rate in both systems increased linearly with K and quadraticaly with N. Also in Florida, Post (1983) studied the nutrient effects comparing conventional-tillage with NT in a rye-soybean succession. The results indicated that the rye-soybean DC system tended to maintain nutrients within the top 0.30 m soil layer. However, a decline of total N and extractable K was observed. The author pointed out that in general, this DC system efficiently recycles nutrients from crop to soil, but long-term yield declines in soybean could be associated with insufficient replenishment of K. In contrast, Wright et al.

(1988) reported that yield of triticale (XTriticosecale Wittmack) varieties responded to the application of 33 kg N ha^{-1} but not to higher N rates or split applications. A soybean crop that followed the triticale crop did not show a visible response to residual K that was applied to the triticale.

Gallaher (1977a) suggested that fertilizer applied to one crop may leave or contribute residual nutrients for a succeeding crop. The objective of this research was to evaluate the long-term N and K application response in a 11-yr-old NT rye-soybean DC system.

Materials and Methods

Simultaneously to the experiment discussed in chapter 3, plots used during the 1985-1986 (85-86) cropping cycle (CC) were planted and sampled again the second year to evaluate the long-term residual effect of fertilizer. Double-cropping of rye and soybean during November 1985 to October 1986 constituted the first CC (85-86) and from November 1986 to October 1987 constituted the residual (R) CC study. Crops were planted for the R CC in the same plots used during the 85-86 CC. Identical data were collected. A randomized complete block design with four replications in a modified 5X5 factorial was used with N assigned at random and K assigned at random within each N treatment. Main plots consisted of two CC (85-86 and R) (Fig 2-2). Sub-plots consisted of five N rates (0, 39, 78, 117, and 156 kg ha^{-1})

each containing five sub-sub-plots of K (0, 45, 90, 135, and 180 kg ha^{-1}). Sub-sub-plots were 3.0 by 5.0 m in size. Nitrogen was applied to the rye crop on both cycles. Potassium was applied only once, to the rye crop during the 85-86 CC. Testing of differences among treatments was made as described in phase I of the materials and methods chapter. The statistical model used was expressed by Eq. [2-2] and Table 2-3:

$$Y_{ijkl} = M + R_i + C_j + N_k + (CN)_{jk} + e_{ijk} + K_l + (CK)_{jl} + (NK)_{kl} + (CNK)_{jkl} + e_{ijkl} \qquad [2-2]$$

Y_{ijkl} = response

M = mean

R = replications $i = 1,2...4$

C_j = cropping cycle $j = 1,2$

N_k = nitrogen $k = 1,2....5$

K_l = potassium $l = 1,2....5$

e = random error

The following model was used to show the curvilinear response to N and the linear response to K when multiple regression techniques were used (Steel and Torrie, 1980):

$$Y = b_0 + b_1 N - b_2 N^2 + b_3 K \qquad [4-1]$$

In this equation, Y is the predicted value and N and K refer to coded rates of fertilizer applied. The b values are the regression coefficients indicating the intercept and the linear and quadratic effects of the applied nutrients.

Results and Discussion

No interactions occurred in this experiment. Higher predicted Y variable values were found for rye WPDM, GY1, GC, HW, GY2, and SY during the 85-86 CC as compared with the R CC. Percent grain head^{-1} showed higher values during the R CC. Rye WPDM and HAI had a curvilinear response to N and a linear response to K during the 85-86, R, and average (avg) CC (Table 4-1). The best combination of factors for predicting these variables in a regression equation according to the model described by Eq. 2-2 was expressed by Eq. [4-1].

Rye GY1 had an analogous behavior to rye WPDM and HAI except for the CC avg which did not show a response to K. The same response expresed by Eq. [1] was showed by: SY R CC, rye GC 85-86 and CC avg, and rye HW R CC (Table 4-1). Soybean seed yield did not respond to the application of N to the rye crop but showed a linear response to residual K during the 85-86 and the CC avg. (Table 4-1) Eq. [4-2].

$$Y = b_0 + b_1 K \qquad [4-2]$$

A linear response to N was observed for rye GC and GY2 during the R CC. However, rye HW and GY2 showed a linear response to both N and K for the 85-86 and CC avg (Table 4-1). A linear response to K was observed for PGH for the R CC and CC avg. Coefficients of determination (R^2) were relatively low in this experiment (Table 4-1). This was mostly due to the high soil variability and the late

Table 4-1. Regression coeficients for linear and quadratic equations predicting long-term yield of rye and soybean.

Cropping cycle	Intercept	N Linear	K Linear	N Quadratic	R^2
			- Rye whole plant dry matter -		
			kg ha^{-1}		
85-86	2449	4.36E+01**	4.16E+00**	-1.38E-01**	0.77
Residual	2934	-3.39E+01**	4.39E+00**	-1.46E-02**	0.44
Avg.	2691	-3.87E+01**	4.28E+00**	-1.42E-01**	0.58
			- Rye grain yield 1 (GY1) -		
			kg ha^{-1}		
85-86	293	6.96E+00**	5.68E-01*	-1.85E-02*	0.57
Residual	177	3.54E+00**	5.28E-01*	-1.73E-02**	0.16
Avg.	235	5.25E+00**	NS	-1.79E-02*	0.22
			- Soybean seed yield -		
			kg ha^{-1}		
85-86	2535	NS	2.40E+00**	NS	0.18
Residual	1516	8.96E+00**	1.42E+00*	-4.89E-02**	0.18
Avg.	2025	NS	1.91E+00**	NS	0.12
			- Rye ground cover -		
			%		
85-86	56	5.32E-01**	3.71E-02*	-1.97E-03**	0.59
Residual	61	1.42E-01**	NS	NS	0.55
Avg.	58	3.37E-01**	3.04E-02*	-1.15E-03**	0.45
			- Rye head area index -		
			$cm^2 m^2$		
85-86	125	2.32E+00**	3.56E-01**	-6.43E-03*	0.53
Residual	157	1.99E+00**	3.31E-01**	-6.17E-03*	0.39
Avg.	141	2.16E+00**	3.44E-01**	-6.30E-03**	0.46
			- Rye head weight[a] -		
			kg ha^{-1}		
85-86	517	3.06E+00**	9.54E-01**	NS	0.39
Residual	167	3.77E+00**	6.54E-01**	-1.56E-02	0.29
Avg.	342	3.42E+00**	8.04E-01**	NS	0.17

Table 4-1--continued.

	- Rye grain yield (GY2)[a] -				
	kg ha^{-1}				
85-86	312	3.65E+00**	1.01E+00*	NS	0.32
Residual	160	2.79E+00*	NS	NS	0.12
Avg.	236	3.22E+00**	8.21E-01*	NS	0.18
	- Percent grain head^{-1}[a]-				
85-86	NS	NS	NS	NS	NS
Residual	32	NS	3.10E-02*	NS	0.11
Avg.	30	NS	2.36E-02*	NS	0.05

*,** Regression coefficients for which coefficients of determination were computed were significant at the 0.05 and 0.01 probability levels respectively; NS = not significant; [a] rye head weight, rye grain yield (GY2), and percent grain head^{-1} were obtained from a harvested area of 0.25 m^2, 1.5 m^2 harvest area was used for all the other variables.

freezes that affected the rye crop during both years of the experiment.

Highest yields of rye WPDM where obtained from 117 kg N ha^{-1} (FPLSD P <0.05) (Table 4-1) for the 85-86, R CC, and CC avg. Response to N increased linearly up to the 117 kg ha^{-1} fertilizer rate and then decreased at the highest N rate (156 kg ha^{-1}). Similar results were observed for rye GY1. Rye WPDM showed a response to K at the 45 kg ha^{-1}, 90 kg ha^{-1}, and 135 kg ha^{-1} for the 85-86, R, and CC avg, respectively (FPLSD 0.05) (Table 4-1). Rye grain yield responded positively to K up to the 135 kg ha^{-1} rate then decreased at the highest K rate for the CC avg.

Soybean seed yield did not respond to N rates in either cropping cycle. However, a trend of greater SY was observed with increasing N rates applied to the rye crop up to the 117 kg N ha^{-1} rate and decreased at the highest rate of 156 kg ha^{-1}. Soybean seed yield showed a response to the residual K at the 45 kg K ha^{-1} and 117 kg ha^{-1} rate for the 85-86 and CC avg, respectively (Table 4-2). This indicated that K applied to the rye crop was cycled through the rye residue and returned to the soil to be used by the succeeding soybean crop for both cycles. These results agreed with Post (1983) who found evidence of nutrient recycling from the previous crop to the succeeding crop in a rye-soybean NT DC system.

Rye PGC responded to the application of 39 kg N ha^{-1} for the 85-86 CC and 117 kg N ha^{-1} for the R CC and CC avg.

Table 4-2. Long-term rye and soybean yield variables as affected by N and K fertilization.

Yield variable	N rate	Cropping cycle			K rate	Cropping cycle		
		85-86	Residual	Avg		85-86	Residual	Avg
Rye WPDM[a]				kg ha^{-1}				
	0	1800	2390	2095	0	3400	3020	3210
	39	3100	4010	3555	45	3900	3440	3670
	78	4300	4010	4155	90	3900	3660	3780
	117	5200	4500	4850	135	4200	3840	4020
	156	5100	3830	4465	180	4100	3810	3955
FPLSD[b]		750	110	620		430	610	370
Rye grain (GY1)				kg ha^{-1}				
	0	390	270	330	0	700	300	500
	39	490	240	365	45	660	310	485
	78	770	410	590	90	740	410	575
	117	1010	470	740	135	740	470	605
	156	930	320	625	180	760	320	540
FPLSD		220	NS	140		110	NS	70
Soybean yield (SY)				kg ha^{-1}				
	0	2210	1300	1755	0	1810	1500	1660
	39	2180	1500	1840	45	2290	1500	1900
	78	2080	1610	1845	90	2240	1410	1825
	117	2350	1770	2060	135	2340	1660	2000
	156	2190	1420	2805	180	2340	1640	1990
FPLSD		NS	NS	NS		400	NS	240
Rye ground cover (GC)	kg ha^{-1}		%		kg ha^{-1}		%	
	0	47	45	46	0	45	51	48
	39	67	48	58	45	70	57	64
	78	75	58	67	90	71	55	63
	117	83	64	74	135	74	59	67
	156	82	65	74	180	72	56	64
FPLSD		17	13	10		6	5	4

Table 4-2--continued.

Rye head area index (HAI)				kg ha^{-1}				
	0	140	170	155	0	200	210	205
	39	180	200	200	45	240	200	220
	78	260	270	265	90	270	270	270
	117	260	270	365	135	260	330	295
	156	320	300	310	180	270	300	285
FPLSD		90	80	50		60	60	30
Rye head weight (HW)[c]				kg ha^{-1}				
	0	600	250	425	0	780	300	540
	39	680	310	495	45	800	350	575
	78	840	420	630	90	900	390	645
	117	1120	500	810	135	880	430	655
	156	980	410	695	180	900	410	655
FPLSD		210	130	120		130	90	80
Rye grain (GY2)[c]				kg ha^{-1}				
	0	400	310	350	0	530	350	440
	39	490	260	375	45	570	330	450
	78	630	440	535	90	750	390	570
	117	1020	520	770	135	650	430	540
	156	780	420	600	180	740	440	590
FPLSD		300	NS	180		170	NS	100
Percent grain head^{-1} [c] (PGH)	kg ha^{-1}		%		kg ha^{-1}		%	
	0	30	42	36	0	35	38	37
	39	29	35	32	45	29	38	34
	78	32	43	38	90	35	41	38
	117	39	42	41	135	34	41	38
	156	38	37	38	180	34	43	38
FPLSD		8	NS	5		6	NS	4

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[a] whole plant dry matter, [b] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$), [c] rye head weight, grain yield (GY2), and percent grain head^{-1} were obtained from a harvested area of 0.25 m^2, 1.5 m^2 harvested area was used for all other variables.

A response to K application of 45 kg ha^{-1} was observed for this variable for all CC. Greater ground cover percentages could be important to protect the soil against water and wind erosion. This could be an important factor when the rye crop is grown for the dual purpose of either dry matter (pasture grazing and/or silage) or grain production and as a winter cover crop for erosion control.

Rye HAI responded to the application of 117 kg N ha^{-1} (Table 4-2). Head area index increased linearly with N during 85-86 and R CC but decreased at the highest N rate of 156 kg N ha^{-1} for the CC avg. Rye HAI responded to the application of 90 kg K ha^{-1} during the 85-86 CC and 135 kg K ha^{-1} the R CC and CC avg. A similar response to N and K was observed for the rye HW (Table 4-2). Because HAI followed a similar pattern to that of rye WPDM and GY1, evidence showed that HAI could be used as a variable for predicting yield of rye.

Rye GY2 showed a response to the application of 117 kg N ha^{-1} during the 85-86 and CC avg. Similar behavior was observed for the R CC. Rye GY2 increased linearly up to the rate of 117 kg N ha^{-1} then decreased at the highest N rate of 156 kg N ha^{-1} (FPLSD <0.05) (Table 4-2). A response of rye GY2 to K application of 90 kg ha^{-1} and 135 kg ha^{-1} was observed for the 85-86 and CC avg (FPLSD 0.05) (Table 4-2). However, a weak linear increase in GY2 was observed during the R CC.

Rye PGH responded to the application of 117 kg N ha^{-1} and 90 kg K ha^{-1} for the 85-86 and CC avg (FPLSD 0.05) (Table 4-2). The total grand mean for the rye PGH was 37 % for CC avg. This could be used to indicate how rye heads reached only about a third of their total potential grain filling capacity. This could be explained by the early increase in temperatures in February and the later freezes in March that occurred during the spring that is usual under the North Central Florida's subtropical climate. Thus, even though the rye heads were fully developed, the rye grain filling process was disrupted by the low temperatures.

Conclusions

Fertilizer had a positive effect on rye grain yields (GY1 and GY2), rye WPDM, rye PGC, HW, PGH, HAI, and SY in this NT DC system. Head area index showed a similar behavior in response to N and K as compared with rye WPDM and rye GY1. This indicated that HAI could be used for predicting rye yield.

Soybean seed yield showed a response to residual K that had been applied to the rye crop. Thus, if K is applied to satisfy the needs of the rye crop, no additional K is needed for the soybean crop. Results from this study suggested that NT DC rye-soybean systems require different management as compare to monocropping either rye or soybean. Researchers should place emphasis on developing and carrying out fertilization programs which take into account nutrient cycling and the residual effect of fertilizers. A rye-soybean NT DC system efficiently recycles nutrients when repeatedly practiced on the same area. However, more research is needed to estimate the magnitude of nutrient losses. Fertilizer extension recommendations should be made to alleviate these losses without applying surplus fertilizer which may not be fully utilized by the crops.

CHAPTER 5
ECONOMICS OF A NO-TILLAGE DOUBLE-CROPPING SYSTEM AFFECTED BY NITROGEN AND POTASSIUM FERTILIZATION

Introduction

To increase the sustainability and profitability of agriculture, double-cropping (DC) and no-tillage (NT) systems are becoming more and more popular in the United States. No-tillage practices, crop rotation, use of cover crops, and residue management have a potential economic impact to maximize income, increase soil and water conservation, and to reduce production costs (Gallaher, 1979; Hesterman, 1986; Frye et al., 1985; Doran et al., 1984). Small grain, particularly wheat [Triticum aestivum (L.) em Thell] followed by soybean [Glycine max (L) Merr.] is one of the most widespread DC systems in the southeast (Gallaher, 1977a; Gallaher 1977b; Hargrove et al., 1982; Touchton and Johnson, 1982). Hairston et al. (1987) carried out an economical analysis on straw management and supplemental N implications in a wheat-soybean DC system in Mississippi. The authors concluded that DC treatments where straw was burned had the greatest net returns with or without supplemental N.

Double-cropping of rye [Secale cereale (L.)] followed by soybean is important in the prevailing warm climate of

Florida (Gallaher et al., 1980; Westberry and Gallaher, 1979; Post, 1983). It has been suggested that fertilizer applied to one crop may positively influence the following crop when DC practices are implemented (Gallaher, 1977a; Hargrove et al., 1983). These effects would help to reduce production costs and increase income. However, there are no research-based, economic fertilizer recommendations for rye-soybean DC systems in Florida. The objective of this research was to evaluate the economics of N and K fertilizer application in a 11-yr-old NT rye-soybean DC system.

Materials and Methods

This experiment tested some specific fertilizer treatments. Some of these treatments included the current Extension Service recommendation for N and K on small grain (78 kg N ha^{-1}, 9 kg P_2O_5 and 90 kg K_2O ha^{-1}), and K on soybean (90 kg K_2O ha^{-1}). These recommendations were derived from tests by the Institute of Food and Agricultural Sciences Extension Soil Testing Laboratory.

The fertilizer treatments for this experiment were the following: (1) 78-9-90 kg ha^{-1} (Extension Service recommendation of N-P-K for the rye crop), (2) 78-0-90 (rye crop recommendation of N and K but minus the P), (3) monocrop fertilizer recommendation for rye (78-9-90) and soybean (0-0-90) applied to each crop during both 85-86 and 86-87 cropping cycles of the experiment, and (4) the best response obtained for either rye whole plant dry matter

(WPDM) or rye grain (GY1) from the factorial study described in phase I of the materials and methods chapter and discussed in chapter 3 (117-0-135 for rye WPDM and 117-0-180 for GY1). The design was a randomized complete block with four replications. Testing of differences among treatments was made by the Fisher Protected Least Significant Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). Economic study of the data were conducted using current fertilizer and crop prices (Dr. R.N. Gallaher, 1987, personal communications).

Results and Discussion

No differences were observed among experimental and extension recommendations treatments for any of the variables tested according to the F-test ($P < 0.05$) (Tables 5-1 and 5-2). The greatest yields for the 2-yr DC avg rye WPDM were obtained when 117 kg N ha^{-1} and 135 kg K ha^{-1} were applied as compared with the other treatments. Net return values for rye WPDM were very similar for all treatments. Greater soybean seed yield (SY), soybean net return, DC yield and DC net return were obtained when 117 kg N ha^{-1} and 135 kg K ha^{-1} were applied to the rye crop (Table 5-1). This indicated that there was no need to apply P and K fertilizer to both the rye and soybean crops in order to obtain either greater yields or net returns from rye WPDM and SY.

Somewhat greater rye GY and net return was observed when the extension fertilizer recommendation including P

Table 5-1. Rye whole plant dry matter (WPDM), soybean yield and dollar net return as affected by experimental and extension fertilizer combinations (2-year average).

Fertilizer			WPDM		Soybean		Double-cropping	
Crop applied to	Rate	Cost	Yield	NR[a]	Yield	NR	Yield	NR
	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-
Rye[b]	78-9-90	93	5104	443	2125	425	7229	868
Rye + Soybean[c]	78-9-90 00-0-90	93 34 127	4983	430	1927	351	6910	781
Rye[d]	78-0-90	81	4918	435	2103	421	7021	856
Rye[e]	117-0-135	122	5355	440	2517	503	7872	943

[a] Net return = gross return (GR) - cost (C), where GR = commodity market price x yield, and C = price per unit of fertilizer x units (kg ha^{-1}) of fertilizer applied; [b] rye extension recommendation; [c] rye + soybean extension recommendation; [d] rye extension recommendations - P; [e] best experimental treatment rye WPDM.

Table 5-2. Rye grain, soybean yield, and dollar net return as affected by experimental and extension fertilizer combinations. (2-year average).

Fertilizer			Grain		Soybean		Double-cropping	
Crop applied to	Rate	Cost	Yield	NR[a]	Yield	NR	Yield	NR
	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-
Rye[b]	78-9-90	93	737	135	2125	425	2862	560
Rye + Soybean[c]	78-9-90 00-0-90	93 34 127	762	143	1927	351	2689	494
Rye[d]	78-0-90	81	622	112	2103	421	2725	533
Rye[e]	117-0-180	139	710	81	2077	483	2787	564

[a] Net return = gross return (GR) - cost (C), where GR = commodity market price x yield, and C = price per unit of fertilizer x units (kg ha^{-1}) of fertilizer applied; [b] Rye extension recommendation; [c] rye + soybean extension recommendations; [d] rye extension recommendations - P; [e] best experimental treatment rye grain.

(78-9-90) and (0-0-90) was applied to the rye crop (Table 5-2). However, greater SY and net return were obtained when the 117-0-180 fertilizer rate was applied to only the rye crop. Combining the rye grain-soybean yields indicated that highest yields were obtained with the application of the 78-9-90 fertilizer treatment. However, the highest net return was observed when 117 kg N ha^{-1} and 180 kg K ha^{-1} were applied to the rye crop (Table 5-2).

Conclusions

Application of P fertilizer was not necessary to obtain greater net returns from rye WPDM, GY, and SY. Also, it was not necessary to apply fertilizer to the soybean crop when fertilizer had been applied to the previous rye crop. Fertilizer had a positive but different effect on both rye and soybean crops in this NT DC system. These results agreed with those suggested by Gallaher (1977a) who felt that fertilizer applied to one crop may leave enough residual nutrients for a succeeding crop, thereby reducing costs to the total multiple-cropping system. Therefore, a different fertilizer management is required for NT DC system as compared with monocropping of either rye or soybean. Researchers should consider the agro-ecological factors involved in DC practices in order to make appropriate recommendations for based on economics DC of rye and soybean.

CHAPTER 6

ECONOMICS OF THE LONG-TERM EFFECT OF NITROGEN AND POTASSIUM FERTILIZATION ON A NO-TILLAGE DOUBLE-CROPPING SYSTEM

Introduction

No-tillage (NT) and double-cropping (DC) practices are influenced by physical, chemical, technical, and economical factors. Economic studies of the profitability of NT small grain followed by soybean [*Glycine max* (L.) Merr.] DC in the southeast United States are scarce. Touchton and Wells (1985) stated that studies designed to improve the profitability of NT systems were still incipient. Sanford (1982) compared costs and net returns of a wheat [*Triticum aestivum* (L.) em Thell]-soybean DC system and the monocropping of soybean in a Mississippi experiment. Hairston et al. (1987) studied the implication of straw management and supplemental N in a wheat-soybean DC system. The economical analysis from that study showed that DC treatments where straw was burned provided the greatest return with or without supplemental N. Blaine et al. (1988) discussed the economics of soybean-wheat intercropping systems.

A large variety of small grain-soybean DC systems [soybean followed by rye [*Secale cereale* (L.)] grain

(Westberry and Gallaher, 1979), wheat after soybean or dormant summer perennial grasses (Wright, 1984), soybean or grain sorghum (Sorghum bicolor L. Moench.) followed by oat (Avena sativa L.) (Ortiz and Gallaher, 1984; Ortiz, 1985), and others suggested by Gallaher et al. (1980)] can be practiced in the predominantly warm climate of Florida. Therefore, soil fertility management of these DC systems is important. Farmers considering NT DC systems should closely consider the net returns associated with these practices as compared with monocropping under conventional-tillage practices. Appropriate fertilizer management of long-term rye-soybean DC systems is necessary in order to obtain the highest profits and benefits. Gallaher (1977a) suggested that fertilizer applied to one crop may leave or contribute residual nutrients for a succeeding crop thus reducing total cost to the multiple-cropping system. The purpose of this research was to evaluate the economics of the long-term effect of N and K fertilizer in a 11-yr-old NT DC system.

Materials and Methods

A similar procedure to that described in phase III of the Materials and Methods chapter was followed in this experiment. However, this experiment dealt with the long-term effect of fertilizer on the same plots during both the 1985-1986 (85-86) and the 1986-1987 residual (R) cropping cycles (CC). The fertilizer treatments for this experiment were the following: (1) 78-9-90 kg ha^{-1} (Extension Service recommendation of N-P-K for the rye crop), (2) 78-0-90 (rye crop recommendation of N and K but minus the P), (3) monocrop fertilizer recommendation for rye (78-9-90) and soybean (0-0-90) applied to each crop during the 85-86 CC, (4) recommended fertilizer for rye (78-0-90) and soybean (0-0-90) applied to each of the crops during both 85-86 and R CC of the experiment, and (5) the best response obtained for either rye whole plant dry matter (WPDM) or rye grain yield (GY1) from the factorial study described in phase I of the materials and methods chapter (180-0-135 for WPDM and 117-0-180 for RG). The design was a randomized complete block with four replications. Testing of differences between treatments was made as described in phase III of the materials and methods chapter. Economic analyses of the data were conducted using the current fertilizer and crop prices (R.N. Gallaher, personal communication).

Results and Discussion

No differences were found between treatments for any of the variables tested according to the F-test ($P > 0.05$). Results of yield and economic evaluations of the long-term residual effect of fertilizer on rye WPDM and soybean seed in relation to experimental and extension fertilizer combinations are shown in Table 6-1. Results indicated that the extension fertilizer recommendation (78-9-90 for the rye crop + 0-0-90 for the soybean crop) applied both years showed the greatest yield (10,998 kg ha^{-1}) for the total sum

Table 6-1. Yield and economics of long-term residual effect of fertilizer on rye whole plant dry matter (WPDM) and soybean seed in relation to experimental and extension fertilizer combinations.

Fertilizer			1985-1986 cropping cycle						Residual 1986-1987 cropping cycle					
Crop applied to	Rate	Cost	Rye WPDM		Soybean		DC^a		Rye WPDM		Soybean		DC	
			Yield	NR^b	Yield	NR	Yield	NR	Yield	NR	Yield	NR	Yield	NR
	-kg ha^{-1}-	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-
Rye	78-9-90^c	43	4997	432	2597	519	7594	951	4803	457	1661	332	6464	789
Rye	78-0-90^d	81	4321	373	2381	476	6702	849	4167	390	1551	302	5678	692
Rye Soybean	78-9-90 + 00-9-90^e	93 34 127	5216	455	2416	449	7632	903	5356	515	1671	334	7026	849
Rye Soybean Rye Soybean	78-9-90 00-0-90 78-9-90 00-0-90^f	93 34 93 34 254	4787	410	2857	537	7644	947	6211	559	1727	311	7938	871
Rye	117-0-135^g	122	5340	439	2873	575	8213	1013	4909	445	1951	390	6860	836

Table 6-1--continued.

Sum of 2-yr cropping cycle					
Rye WPDM		Soybean		DC	
Yield	NR	Yield	NR	Yield	NR
kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-
9800	898	4258	852	14058	1750
8488	763	3892	778	12380	1542
10572	970	4087	783	14659	1753
10998	969	4584	848	15582	1807
10249	884	4823	964	15072	1848

[a] Double-cropping; [b] net return = gross return (GR) - cost (C), where GR = commodity market price x yield, and C = price per unit of fertilizer x units (kg ha^{-1}) of fertilizer applied; [c] rye monocrop extension recommendation; [d] rye monocrop extension recommendation without P; [e] rye and soybean extension recommendations applied to both crops, respectively only the first cropping cycle; [f] rye and soybean extension recommendations applied to both crops, respectively on both cropping cycles of the experiment; [g] best experimental treatment from the factor factorial analysis.

of 2-yr data for rye WPDM. However, the extension recommendation applied only during the first year showed the highest net return ($ 970) as compared with the other treatments for rye WPDM (Table 6-1). Fertilizer P seems to be needed when rye is grown for WPDM purposes. Highest 2-yr SY and net returns were observed when 117 kg N ha^{-1} and 135 kg K ha^{-1} were applied to the rye crop. Highest 2-yr DC yields were observed when extension fertilizer recommendations of NPK were applied to both crops during both years. Nevertheless, slightly higher net return for the 2-yr DC was observed when 117 kg N ha^{-1} and 135 kg K ha^{-1} were applied to the rye crop. The application of greater rates of N and K fertilizer as compared with the extension N and K rates enhanced the P uptake by the rye and soybean crops. A better extraction of soil P occurred when greater rates of N and K fertilizer were applied. Thus, P fertilizer was not needed in order to obtain highest net returns.

Highest 2-yr rye GY and net return was obtained with the application of 117 kg N ha^{-1} and 180 kg K ha^{-1} applied to the rye crop during the first year (Table 6-2). Highest 2-yr SY was obtained when 78 kg N ha^{-1} and 90 kg K ha^{-1} were applied to the rye crop, but the highest net return was obtained when the same rate of fertilizer including 9 kg P ha^{-1} was applied. Highest yield of the 2-yr DC system was observed when extension fertilizer recommendation rates were applied to both crops during both years. Nevertheless, highest 2-yr net returns where obtained when 117 kg N ha^{-1}

Table 6-2. Yield and economics of long-term residual fertilizer effect on rye grain and soybean seed in relation to experimental and extension fertilizer combinations.

Fertilizer			1985-1986 cropping cycle						Residual 1986-1987 cropping cycle					
			Rye grain		Soybean		DC[a]		Rye grain		Soybean		DC	
Crop applied to	Rate	Cost	Yield	NR[b]	Yield	NR	Yield	NR	Yield	NR	Yield	NR	Yield	NR
	-kg ha^{-1}-	-$-	kg ha^{-1}	-$-	kg ha^{-1}	-$-	kg ha^{-1}	-$-	kg ha^{-1}	-$-	kg ha^{-1}	-$-	kg ha^{-1}	-$-
Rye	78-9-90[c]	43	744	142	2597	519	3341	661	554	125	1661	333	2215	458
Rye	78-0-90[d]	81	766	156	2381	476	3147	633	394	77	1511	302	1910	379
Rye Soybean	78-9-90 + 00-9-90[e]	93 34 127	765	144	2416	449	3181	593	603	140	1671	334	2279	474
Rye Soybean Rye Soybean	78-9-90 00-0-90 78-9-90 00-0-90[f]	93 34 93 34 254	708	167	2857	537	3565	664	806	157	1727	345	2533	502
Rye	117-0-180[g]	139	1008	174	2375	477	3383	651	599	116	1851	370	2450	486

Table 6-2--continued.

Sum of 2-yr cropping cycles					
Rye grain		Soybean		DC	
Yield	NR	Yield	NR	Yield	NR
kg ha^{-1}	-\$-	kg ha^{-1}	-\$-	kg ha^{-1}	-\$-
1298	267	4258	852	5556	1119
1165	234	4642	778	5807	1010
1369	284	4087	783	5455	1067
1514	284	4584	838	6098	1122
1607	290	4226	845	5833	1137

[a] Double-cropping; [b] net return = gross return (GR) - cost (C), where GR = commodity market price x yield, and C = price per unit of fertilizer x units (kg ha^{-1}) of fertilizer applied; [c] rye monocrop extension recommendation; [d] rye monocrop extension recommendation without P; [e] rye and soybean extension recommendations applied to both crops, respectively only the first cropping cycle; [f] rye and soybean extension recommendations applied to both crops respectively on both cropping cycles of the experiment; [g] best experimental treatment from the factor factorial analysis.

and 180 kg K ha^{-1} were applied to the rye crop during the 85-86 CC only (Table 6-2). This suggested that a long-term N and K nutrient cycling occurred and affected rye WPDM, rye GY, and SY when greater N and K rates as compared with the extension fertilizer rates were applied.

Conclusions

Rye WPDM, GY1, and SY showed a positive response to the application of N and K. Application of P was not necessary to obtain greater net dollar returns of rye WPDM, rye GY, and SY. These results showed that a NT DC system requires different fertilizer management as compared with monocropping systems of either rye or soybean. Potassium can be applied to the rye crop in order to satisfy the needs of both rye and the following crop of soybean. Nitrogen is needed by the rye crop every time it is grown in this sandy soil. Phosphorus fertilizer was not needed when higher N and K fertilizer rates as compared with the extension fertilizer rates were applied.

CHAPTER 7

LONG-TERM EFFECT OF N AND K FERTILIZER IN A NO-TILLAGE RYE-SOYBEAN DOUBLE-CROPPING SYSTEM

Introduction

Small grain-soybean [Glycine max (L.) Merr.] has become a common multiple-cropping practice in the southeastern U.S.A. (Gallaher 1977a; Gallaher 1977b; Gallaher and Weaver, 1982; Hargrove et al., 1982; NeSmith et al., 1987). Rye [Secale cereale (L.)] followed by soybean is an important double-cropping (DC) system in Florida. There appears to be few studies of rye double-cropped with soybean compared with other small grain crops DC with soybean.

The success of conservation tillage practices for monocropping and DC systems is dependent on soil type, moisture, residue management and fertilizer history (Dick and Van Doren, 1985; Gallaher 1977b, Unger, 1984; Webber et al., 1987; Benoit and Lindstrom 1987, and Hairston et al., 1987). Greater grain yields were achieved when wheat and soybean were DC compared with monocropped wheat and soybean (Crabtree and Rupp, 1980). Gallaher (1977a) and Hargrove et al. (1983) discussed the importance of the residual effect of fertilizer applied to one crop and its influence on the following crop when grown as a DC system. Sanford and

Hairston (1984) found higher grain yield, straw yield, plant height, and N uptake when wheat [Triticum aestivum (L.)] followed soybean. In contrast, Singh and Rajat De (1982) reported little or no residual effect of N in a pearlmillet [Pennissetum glaucum (L.)]-wheat DC system. Mugwira et al. (1980) indicated that triticale (XTriticosecale Wittmack), rye, and wheat [Triticum aestivum (L.)] were similar in nitrate uptake in a cultivar study.

Nitrogen concentration in the soil surface is usually higher under no-tillage (NT) than under conventional-tillage (CT) (Dick, 1983; Ferrer, 1984; Ortiz and Gallaher, 1984). Blevins et al. (1977) showed that soil N was significantly higher under NT and increased with increased rates of fertilizer applied. Power et al. (1986) described the uptake of N from soil, fertilizer, and crop residues by NT corn [Zea mays (L.)] and soybean. They found that grain and straw production of both crops increased as crop residue rates increased.

Bharati et al. (1986) found that soybean responded to K application in soils that showed medium to high soil-test K levels. Potassium application increased soil and soybean leaf K content over time and with increased application levels. Gallaher and Jellum (1976a, 1976b) studied the elemental and cation ratio effects on corn hybrids and reported that concentrations of Ca, Mg, and K in corn leaf tissue appeared to be positively related to soil levels. Sallam et al. (1985) showed that the net fluxes of K in soybean vary with transport pathway within the plant and with plant age. Similarly, Scott and Brewer (1980) stated that the accumulation of N and K in soybean is essentially linear over time during most of the growing season.

Conflicting reports regarding K concentration and distribution at different soil depths as influenced by tillage practices have been found in the literature (Triplett and Van Doren, 1969; Hargrove et al., 1982; Ferrer, 1984; Ortiz and Gallaher, 1985). Apparently, there is not a clear consensus about K behavior on different soils and under different tillage practices. Vasilas et al. (1988) studied four tillage systems and soybean response to K fertility. They concluded that the tillage system should not influence K fertility recommendations for the Mollisols where they conducted the experiment. Elwali and Gascho (1985) evaluated the timing and rate of K application for wheat-soybean DC on a sandy soil. Increasing rates of K linearly increased wheat yield. It was also found that soil K increased as rates of K increased when measured at soybean planting time. However, no significant effects on soybean yield and soil K were found at the end of the season.

The objective of this experiment was to study the long-term effect of N and K fertilization in a rye-soybean DC system under NT conditions.

Materials and Methods

Prior to initial application of treatments described in phase II of the materials and methods chapter, soil samples were collected from the 0.00 to 0.05, 0.05 to 0.10, 0.10 to 0.15, 0.15 to 0.30, 0.30 to 0.45, and 0.45 to 0.60 m depths for analysis of soil N and K. Soil samples were also taken to a depth of 0.60 m in November 1985, 1986, and 1987 immediately following the soybean harvest and to a depth of 0.30 m in May 1986 and 1987 immediately after the rye crop (Table 2-4, Fig. 2-2). Samples were air dried and sieved to pass a 0.002 m stainless steel screen.

Rye tissue samples were collected at tillering and early bloom stages in 1986 and 1987. Soybean tissue samples were collected at the R2 stage (full bloom) (Fehr and Caviness, 1977) in 1986 and 1987. Samples of rye grain and soybean seed were collected at harvest time in 1986 and 1987. Samples were dried at 70 C in a forced-air oven, ground using a Wiley mill, and analyzed for N and K.

Soil and plant N was analyzed by using a Kjeldahl digestion unit (Gallaher et al., 1975; Gallaher et al., 1976) followed by colorimetric determination by a Technicon II AutoAnalyzer. Soil K was determined by double acid (Mehlich I) extraction (Mehlich, 1953) followed by flame emission spectrophotometry. Plant K was determined by dry ashing, followed by acid extraction and flame emission spectrophotometry (Jones and Steyn, 1983). Testing of differences among treatments was made by the Fisher

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Protected Least Significant Test (FPLSD) (Steel and Torrie, 1980; Chew, 1976). When ANOVA indicated a significant ($P < 0.05$) treatment effect, regression was used for comparing treatment means of plant variables.

Results and Discussion

Soil Nitrogen

Nitrogen vs. sampling time interactions

Interactions between N treatments and sampling time were observed at the 0-5, 10-15, and 15-30 cm depth (F-test, $P< 0.05$) (Table 7-1, Fig.7-1). Higher N concentrations were found at the 0-5 cm depth when 39 kg N ha^{-1} were applied for the 183, 365, and 548 days. Higher N concentrations were found at the 78 and 156 kg ha^{-1} N rates for the 365 and 730 days. A similar effect was found at the 156 kg ha^{-1} N rate at the 730 days.

In general, N concentration in the soil was lower following rye as compared with immediately following soybean (Fig. 7-1). There was greater plant N uptake from the soil when the rye crop was grown. Greater N depletion from the soil was observed during the growth periods where higher levels of N fertilizer were applied. This effect was even more pronounced for the 85-86 cropping cycle (CC).

The higher N concentration observed following soybean indicated a greater N return to the soil. This was especially true at the highest rates of N. These results were similar to those reported by Sanford and Hairston (1984) who found a greater availability of N following

Table 7-1. Long-term soil N, N rate vs time interactions.

	N rate						
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
Time days[b]	g N kg^{-1}						
	0-5 cm						
0	0.78	0.77	0.81	0.77	0.78	0.78	6.7E-02
183	0.77	0.79	0.74	0.71	0.72	0.75	6.7E-02
365	0.80	0.86	0.81	0.79	0.85	0.81	6.7E-02
548	0.78	0.82	0.78	0.75	0.73	0.75	6.7E-02
730	0.78	0.73	0.83	0.72	0.88	0.77	6.7E-02
Avg.	0.77	0.79	0.80	0.75	0.78		
FPLSD	6.7E-02	6.7E-02	6.7E-02	6.7E-02	6.7E-02		
	5-10 cm						
0	0.60	0.57	0.58	0.58	0.58	0.58	NS
183	0.51	0.46	0.44	0.50	0.51	0.49	NS
365	0.58	0.50	0.56	0.53	0.53	0.54	NS
548	0.52	0.47	0.50	0.50	0.50	0.49	NS
730	0.52	0.46	0.54	0.49	0.56	0.51	NS
Avg.	0.55	0.49	0.53	0.52	0.54		
FPLSD	NS	NS	NS	NS	NS		
	10-15 cm						
0	0.49	0.49	0.50	0.52	0.49	0.50	6.7E-02
183	0.41	0.39	0.36	0.39	0.34	0.38	6.7E-02
365	0.41	0.39	0.39	0.45	0.41	0.41	6.7E-02
548	0.39	0.38	0.41	0.42	0.40	0.40	6.7E-02
730	0.37	0.34	0.37	0.39	0.38	0.37	6.7E-02
Avg.	0.41	0.40	0.40	0.43	0.40		
FPLSD	6.7E-02	6.7E-02	6.7E-02	6.7E-02	6.7E-02		

Table 7-1--continued.

	N rate						
	kg ha^{-1}						
Time days[b]	0	39	78	117	156	Avg.	FPLSD[a]
	g N kg^{-1}						
	15-30 cm						
0	0.41	0.37	0.39	0.39	0.41	0.39	6.7E-02
183	0.24	0.24	0.26	0.28	0.29	0.26	6.7E-02
365	0.33	0.22	0.28	0.25	0.24	0.27	6.7E-02
548	0.28	0.25	0.26	0.25	0.28	0.26	6.7E-02
730	0.25	0.24	0.27	0.23	0.27	0.25	6.7E-02
Avg.	0.30	0.27	0.29	0.28	0.30		
FPLSD	6.7E-02	6.7E-02	6.7E-02	6.7E-02	6.7E-02	6.7E-02	
	30-45 cm						
0	0.33	0.31	0.33	0.31	0.34	0.32	NS
365	0.23	0.34	0.31	0.23	0.22	0.27	NS
730	0.21	0.17	0.27	0.16	0.21	0.20	NS
Avg.	0.28	0.26	0.23	0.26	0.29		
FPLSD	NS	NS	NS	NS	NS		
	45-60 cm						
0	0.32	0.34	0.30	0.30	0.30	0.31	NS
365	0.19	0.15	0.15	0.15	0.15	0.16	NS
730	0.15	0.16	0.16	0.16	0.13	0.17	NS
Avg.	0.22	0.22	0.21	0.19	0.21		
FPLSD	NS	NS	NS	NS	NS		

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[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$); [b] 0 days = initial, 183 days = rye 1985-86, 365 days = soybean 1986, 548 days = rye 1986-87, 730 days = soybean 1987.

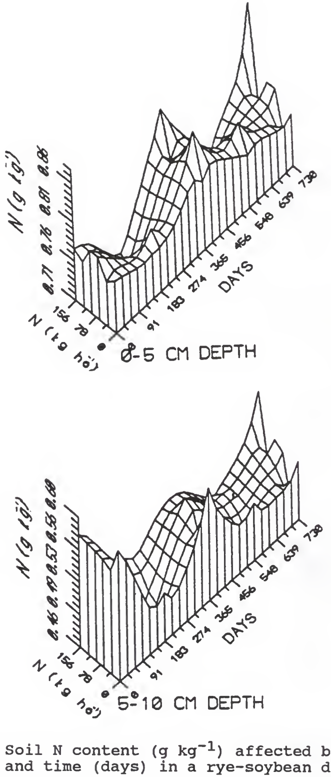
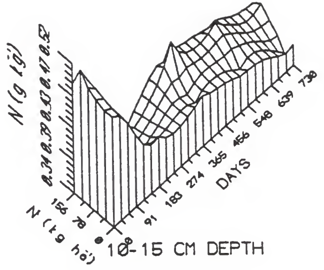


Fig. 7-1. Soil N content (g kg^{-1}) affected by fertilizer N (kg ha^{-1}) and time (days) in a rye-soybean double-cropping system.



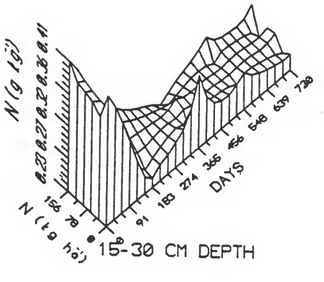


Fig. 7-1--continued.

soybean in a soybean-wheat DC system. Similar results were observed in the 5-10 cm depth.

There was a trend for higher soil N at the 0 kg ha^{-1} level of fertilizer for the 5-10, 10-15, and 15-30 cm depth on most sampling times. The application of N fertilizer to the soil not only induced the uptake of the fertilizer N by the crop plants but also increased the uptake of native soil N. Apparently the healthier plants had more extensive and vigorous root systems.

Soil N was depleted over time in the 15-60 cm zone, opposite the effect in the 0-5 cm depth. This indicated that N was removed from subsoil and accumulated in the 0-5 cm depth over the 2-yr period.

The effect of different crops was not as pronounced at the 30-45 and 45-60 cm depth as occurred in the upper soil layers. Bruniard and Gallaher (1988) showed that NT soybean and oat (Avena sativa L.) roots were located in the upper 10 cm soil layer for soybean and the upper 5 cm for oat. A similar root distribution probably occurred in this 11-yr old rye-soybean experiment; therefore, the plants roots did not extract nutrients at these levels.

Nitrogen concentration decreased over time and crop rotations in the 10-15 and 15-30 cm depth. Nitrogen concentration in the soil was higher before any fertilizer had been applied. This decreasing N concentration in relation to the initial soil N concentration was observed at all depths except the 0-5 cm soil depth. This indicated that N possibly was removed from the soil through crop harvesting. Nitrogen concentration decreased as soil depth increased.

Soil Potassium

Nitrogen vs. sampling time interaction

In general, greater amounts of extractable K were found in the soil following rye crops and depleted after the soybean crop. Interactions between N rates and sampling time for extractable K were observed at the 10-15 and 15-30 cm depth (F-test, $P<0.05$) (Table 7-2, Fig. 7-2). Higher extractable K was observed for the 183 days sampling time at the 0 kg N ha^{-1} rate of N fertilizer for the 10-15 cm depth. Higher extractable K was found for the 0 kg N ha^{-1} rate of fertilizer during the 183 and 548 days sampling time because of poor plant growth. Similar behavior was observed at the 15-30 cm depth.

Dibb and Thompson (1985) showed that a common interaction between N and K is the necessity of adequate levels of K as N rates are increased. Extractable K in the 0-5 cm depth increased as N fertilizer rates applied increased on these sampling times. In contrast, less extractable K was observed as N rates increased at the depths from 5-60 cm depth. This indicated that increasing levels of N fertilizer stimulated the uptake of K from lower depths. Potassium was returned to the soil surface through decaying rye plant residues. These results agreed with those

Table 7-2. Long-term extractable soil K, N rate vs time interactions

	N rate						
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
Time days[b]	g K kg^{-1}						
	0-5 cm						
0	0.035	0.033	0.028	0.034	0.032	0.033	NS
183	0.040	0.046	0.040	0.041	0.050	0.043	NS
365	0.032	0.029	0.028	0.032	0.027	0.030	NS
548	0.039	0.033	0.034	0.038	0.038	0.030	NS
730	0.025	0.025	0.027	0.028	0.027	0.026	NS
Avg.	0.034	0.033	0.032	0.038	0.035	0.026	
FPLSD	NS	NS	NS	NS	NS	NS	
	5-10 cm						
0	0.024	0.022	0.018	0.022	0.021	0.021	NS
183	0.023	0.022	0.022	0.022	0.022	0.021	NS
365	0.018	0.017	0.018	0.023	0.017	0.018	NS
548	0.024	0.018	0.015	0.018	0.020	0.019	NS
730	0.020	0.020	0.017	0.021	0.018	0.019	NS
Avg.	0.022	0.020	0.018	0.021	0.020		
FPLSD	NS	NS	NS	NS	NS		
	10-15 cm						
0	0.018	0.017	0.014	0.014	0.022	0.017	0.009
183	0.029	0.021	0.016	0.016	0.014	0.019	0.009
365	0.014	0.016	0.016	0.014	0.017	0.017	0.009
548	0.022	0.016	0.017	0.014	0.019	0.017	0.009
730	0.017	0.014	0.016	0.014	0.019	0.017	0.009
Avg.	0.020	0.017	0.016	0.017	0.016		
FPLSD	0.009	0.009	0.009	0.009	0.009		

Table 7-2--continued.

	N rate						
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
Time days[b]	g K kg^{-1}						
	15-30 cm						
0	0.017	0.017	0.013	0.014	0.013	0.015	0.004
183	0.019	0.013	0.011	0.009	0.013	0.013	0.004
365	0.016	0.014	0.013	0.013	0.014	0.014	0.004
548	0.015	0.012	0.012	0.012	0.013	0.013	0.004
730	0.014	0.013	0.012	0.012	0.016	0.013	0.004
Avg.	0.016	0.014	0.012	0.012	0.014		
FPLSD	0.004	0.004	0.004	0.004	0.004		
	30-45 cm						
0	0.014	0.013	0.013	0.012	0.015	0.013	NS
365	0.017	0.013	0.012	0.014	0.015	0.014	NS
730	0.013	0.012	0.014	0.011	0.014	0.013	NS
Avg.	0.015	0.012	0.013	0.012	0.015		
FPLSD	NS	NS	NS	NS	NS		
	45-60 cm						
0	0.019	0.014	0.013	0.011	0.017	0.015	NS
365	0.015	0.014	0.010	0.013	0.012	0.013	NS
730	0.013	0.010	0.010	0.009	0.013	0.011	NS
Avg.	0.016	0.013	0.011	0.011	0.014		
FPLSD	NS	NS	NS	NS	NS		

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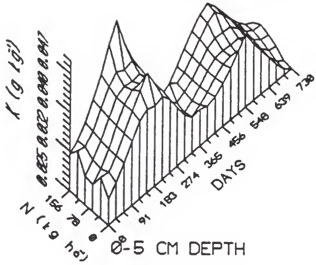
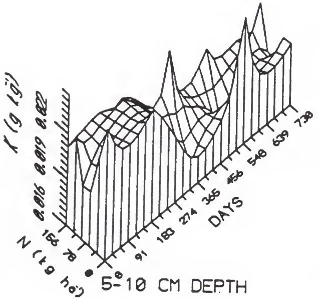
[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$); [b] 0 days = initial, 183 days = rye 1985-86, 365 days = soybean 1986, 548 days = rye 1986-87, 730 days = soybean 1987.

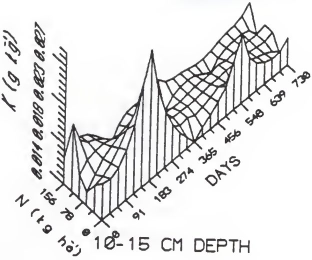


0-5 CM DEPTH



5-10 CM DEPTH

Fig. 7-2. Extractable soil K (g kg^{-1}) affected by fertilizer N (kg ha^{-1}) and time (days) in a rye-soybean double-cropping system.



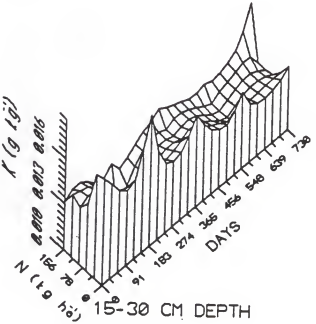


Fig. 7-2--continued.

reported by Ortiz and Gallaher (1985) in an oat-grain sorghum [Sorghum bicolor (L.) Moench] DC system.

Potassium vs sampling time interaction

Applying K at all rates generally increased soil K at all levels. However, interactions between extractable K and sampling time were found at the 5-10, 10-15, and 15-30 cm depth, respectively (F test, $P<0.05$) (Table 7-3, Fig. 7-3). Higher extractable K was observed at the 135 and 180 kg ha^{-1} rates of K fertilizer for the 183 days sampling time in these three depths. A similar trend was observed at the 365 and 730 days for the 30-45 cm depth.

Greater extractable K was found at the 183 and 548 days sampling time at the 0-5 cm depth. A similar trend was observed at the 5-10 and 15-30 cm depth. Potassium was taken up by the rye crop from lower depths and deposited in the 0-5 cm depth through plant residue cycling. Potassium was depleted from the 5-10 and 10-15 cm depth after the first sampling time. This could be explained by a strong K uptake from these depths by soybean during the 85-86 CC. A trend of increasing extractable K as rates of K fertilizer increased was observed at a depth of 5-45 cm following the second soybean crop. Potassium was efficiently conserved in this DC system under NT conditions.

Plant N

A positive linear response to N fertilizer was observed for the rye at the tillering growth stage (Table 7-4). This response was obtained during both 85-86 and the residual CC.

Table 7-3. Long-term extractable soil K, K rate vs time interactions

	K rate						
	kg ha^{-1}						
	0	45	90	135	180	Avg.	FPLSD[a]
Time days[b]	g K kg^{-1}						
	0-5 cm						
0	0.031	0.035	0.031	0.034	0.031	0.033	NS
183	0.046	0.041	0.045	0.040	0.044	0.043	NS
365	0.025	0.028	0.028	0.033	0.034	0.030	NS
548	0.030	0.040	0.034	0.039	0.039	0.036	NS
730	0.023	0.026	0.025	0.027	0.031	0.026	NS
Avg.	0.031	0.034	0.032	0.034	0.036		
FPLSD	NS	NS	NS	NS	NS		
	5-10 cm						
0	0.020	0.026	0.020	0.021	0.020	0.021	0.007
183	0.016	0.020	0.022	0.027	0.028	0.022	0.007
365	0.015	0.017	0.018	0.020	0.020	0.018	0.007
548	0.015	0.020	0.017	0.021	0.021	0.019	0.007
730	0.017	0.018	0.018	0.020	0.022	0.022	0.007
Avg.	0.017	0.020	0.019	0.022	0.022		
FPLSD	0.007	0.007	0.007	0.007	0.007		
	10-15 cm						
0	0.016	0.018	0.018	0.019	0.016	0.018	0.007
183	0.012	0.016	0.018	0.026	0.025	0.019	0.007
365	0.014	0.015	0.017	0.018	0.019	0.017	0.007
548	0.014	0.015	0.015	0.016	0.017	0.015	0.007
730	0.016	0.016	0.017	0.018	0.021	0.017	0.007
Avg.	0.014	0.016	0.017	0.020	0.020		
FPLSD	0.007	0.007	0.007	0.007	0.007		

Table 7-3. continued.

	K rate						
	kg ha^{-1}						
	0	45	90	135	180	Avg.	FPLSD
Time days[b]	g K kg^{-1}						
	15-30 cm						
0	0.013	0.018	0.015	0.016	0.016	0.015	0.005
183	0.009	0.011	0.012	0.016	0.016	0.013	0.005
365	0.011	0.013	0.014	0.016	0.016	0.014	0.005
548	0.011	0.013	0.011	0.014	0.014	0.013	0.005
730	0.011	0.012	0.014	0.015	0.015	0.013	0.005
Avg.	0.011	0.014	0.013	0.015	0.016		
FPLSD	0.005	0.005	0.005	0.005	0.005		
	30-45 cm						
0	0.013	0.014	0.012	0.014	0.014	0.013	NS
365	0.011	0.013	0.014	0.015	0.017	0.014	NS
730	0.011	0.014	0.013	0.014	0.015	0.013	NS
Avg.	0.011	0.014	0.013	0.014	0.015		
FPLSD	NS	NS	NS	NS	NS		
	45-60 cm						
0	0.013	0.017	0.014	0.013	0.017	0.015	NS
365	0.009	0.016	0.014	0.013	0.013	0.013	NS
730	0.009	0.012	0.012	0.011	0.012	0.011	NS
Avg.	0.010	0.014	0.013	0.012	0.015		
FPLSD	NS	NS	NS	NS	NS		

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[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$); [b] 0 days = initial, 183 days = rye 1985-86, 365 days = soybean 1986, 548 days = rye 1986-87, 730 days = soybean 1987.

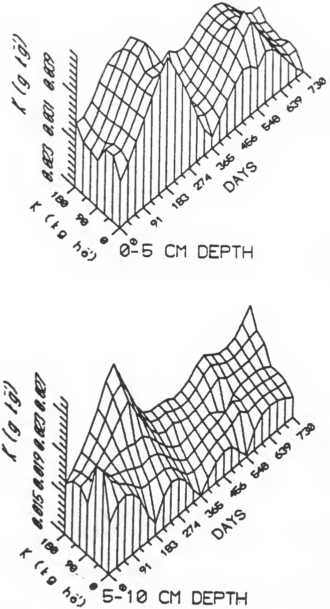
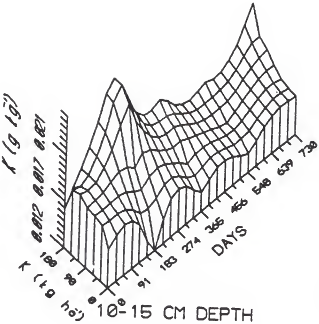
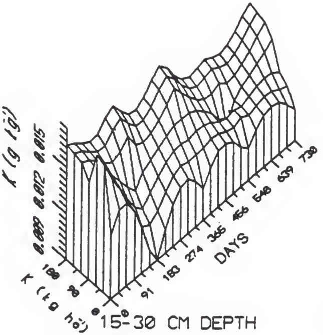


Fig. 7-3. Extractable soil K (g kg^{-1}) affected by fertilizer K (kg ha^{-1}) and time (days) in a rye-soybean double-cropping system.



10-15 CM DEPTH



15-30 CM DEPTH

Fig. 7-3--continued.

Table 7-4. Regression coefficients for equations predicting N concentration in rye and soybean plants.

Cropping Cycle	Intercept	N linear	K linear	N quadratic	NXK	R^2
	---------------	---------------	g N kg^{-1}	---------------	---------------	---------------
			Rye tillers			
85-86	23.6	1.85E-01	NS	NS	NS	0.86
Residual	21.0	2.22E-01	NS	NS	NS	0.80
			Rye flag leaf			
85-86	32.6	3.33E-02	NS	2.73E-04	NS	0.75
Residual	29.5	1.67E-01	NS	-3.20E-04	NS	0.74
			Rye grain			
85-86	26.0	-6.33E-02	-1.03E-03	4.66E-04	NS	0.45
Residual	26.3	NS	-1.38E-02	NS	NS	0.30
			Soybean leaf			
85-86	37.5	NS	2.68E-02	NS	NS	0.13
Residual	NS	NS	NS	NS	NS	NS
			Soybean seed			
85-86	70.0	4.45E-02	NS	-2.65E-04	NS	0.13
Residual	NS	NS	NS	NS	NS	NS

NS = not significant (P. >0.05).

A curvilinear response to N was found for rye flag leaf and soybean seed. Rye grain showed a curvilinear response to N rates and a linear response to K rates during the 85-86 CC but only responded to K fertilization during the residual CC. Soybean leaf only responded to K during the 85-86 CC with a negative curvilinear response.

Nitrogen vs K interactions

Nitrogen vs K interactions were found for the rye tillers, rye flag leaf, and soybean seed during the 85-86 CC. Rye flag leaf from the residual CC also showed an NxK interaction (F test, $P<0.05$) (Tables 7-5 and 7-6, Fig. 7-4). Nitrogen in plants increased as N fertilizer rates increased for all these variables except for soybean seed. Greater N concentration was observed at the 117 kg ha^{-1} rate of N fertilizer and 45, 90, and 135 kg K ha^{-1} for the soybean seed. However, the application of K fertilizer did not show any increase in N uptake for the rye tillers and rye flag leaf variables. However, a trend of greater K uptake as rates of K fertilizer increased was observed for the soybean seed.

Rye tillers showed a curvilinear response to N fertilizer, a linear response to K, and an interaction between N and K during the 85-86 CC (Table 7-7). Similar response was found for rye tillers residual but the NK interaction did not occur. Rye flag leaf responded linearly to the application of N and K fertilizer during the 85-86 CC

Table 7-5. Long-term plant N, fertilizer N vs applied K interactions 85-86 cropping cycle.

K Rate	Fertilizer N						
	-----kg ha^{-1}-----						
	0	39	78	117	156	Avg.	FPLSD[a]
	-----g N kg^{-1}-----						
	Rye Tillers						
0	25.8	25.2	39.2	44.9	44.9	36.0	3.7
45	24.5	25.2	36.0	44.2	45.3	35.1	3.7
90	23.7	25.0	37.0	44.9	45.6	35.3	3.7
135	25.1	25.0	37.0	44.9	45.6	35.3	3.7
180	24.4	24.9	34.8	41.5	45.8	34.4	3.7
Avg.	24.7	25.0	36.9	43.5	44.6		
FPLSD	3.7	3.7	3.7	3.7	3.7		
	Rye flag Leaf						
0	34.3	30.0	38.0	41.3	43.2	37.4	4.8
45	32.0	33.4	38.1	41.9	44.0	37.8	4.8
90	32.5	32.6	37.9	40.5	43.5	37.4	4.8
135	33.2	32.7	37.8	40.8	43.5	37.6	4.8
180	31.5	31.3	37.6	35.4	46.6	36.4	4.8
Avg.	32.7	32.0	37.9	40.0	44.1		
FPLSD	4.8	4.8	4.8	4.8	4.8		
	Rye grain						
0	25.0	24.5	24.0	24.2	26.2	24.8	NS
45	25.2	24.2	24.6	25.3	27.8	25.4	NS
90	25.0	25.0	23.1	23.4	28.0	24.9	NS
135	24.4	22.6	23.9	24.3	27.8	24.6	NS
180	24.4	22.7	22.5	21.5	27.9	23.8	NS
Avg.	24.8	23.8	23.6	23.8	27.6		
FPLSD	NS	NS	NS	NS	NS		

Table 7-5--continued.

K Rate	Fertilizer N						
	---------kg ha^{-1}---------						
	0	39	78	117	156	Avg.	FPLSD[a]
	---------g N kg^{-1}---------						
	Soybean leaf						
0	40.3	35.3	37.8	36.7	38.7	37.8	NS
45	37.2	40.6	39.1	39.0	38.4	38.9	NS
90	38.6	42.6	41.6	40.0	38.2	40.2	NS
135	41.1	42.2	39.8	42.4	39.2	41.0	NS
180	41.7	43.1	42.5	39.3	40.7	41.5	NS
Avg.	39.8	40.7	40.2	39.5	39.0		
FPLSD	NS	NS	NS	NS	NS		
	Soybean seed						
0	69.3	72.7	68.9	72.6	71.3	71.0	4.4
45	70.2	72.1	71.4	73.2	66.3	70.6	4.4
90	70.0	73.0	67.3	73.4	69.3	70.1	4.4
135	71.3	72.5	70.6	73.4	69.3	71.4	4.4
180	71.3	71.9	70.0	69.4	67.9	70.0	4.4
Avg.	70.4	72.4	70.0	72.4	68.8		
FPLSD	4.4	4.4	4.4	4.4	4.4		

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[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$).

Table 7-6. Long-term plant N, fertilizer N vs applied K interactions for the residual cropping cycle.

K	Fertilizer N						
Rate							
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
	g N kg^{-1}						
	Rye tillers						
0	23.3	22.2	41.5	46.3	53.0	37.3	NS
45	22.2	24.4	44.7	45.4	50.7	37.5	NS
90	21.3	24.1	43.0	46.2	56.3	38.2	NS
135	25.6	25.2	41.4	44.4	52.4	37.8	NS
180	21.2	22.4	40.9	44.8	54.1	36.7	NS
Avg.	22.7	23.6	42.3	45.4	53.3		
FPLSD	NS	NS	NS	NS	NS		
	Rye flag leaf						
0	32.6	30.9	40.5	47.2	43.7	39.0	6.1
45	30.1	31.9	40.8	48.2	47.1	39.6	6.1
90	28.6	33.1	42.6	50.7	47.7	40.6	6.1
135	34.8	35.1	41.6	48.7	46.5	41.3	6.1
180	30.9	31.5	41.6	42.0	47.6	38.7	6.1
Avg.	31.4	32.5	41.4	47.4	46.5		
FPLSD	6.1	6.1	6.1	6.1	6.1		
	Rye grain						
0	26.1	25.7	27.0	27.6	30.2	27.4	NS
45	25.6	25.9	28.8	27.4	27.9	27.1	NS
90	25.4	25.8	25.6	27.0	29.8	26.8	NS
135	24.5	24.9	25.4	26.3	28.0	25.8	NS
180	23.6	24.5	24.7	26.6	28.8	25.6	NS
Avg.	25.3	25.4	26.3	27.0	28.9		
FPLSD	NS	NS	NS	NS	NS		

Table 7-6--continued

K Rate	Fertilizer N						
kg ha^{-1}							
	0	39	78	117	156	Avg.	FPLSD[a]
	g N kg^{-1}						
	Soybean leaf						
0	42.5	39.9	39.5	41.4	43.1	41.3	NS
45	43.0	42.0	38.6	42.7	41.0	41.5	NS
90	40.5	44.2	41.9	42.4	40.3	41.8	NS
135	43.3	40.8	38.5	41.9	41.5	41.2	NS
180	44.5	44.2	41.3	41.2	43.8	43.0	NS
Avg.	42.7	42.2	40.0	41.9	41.9		
FPLSD	NS	NS	NS	NS	NS		
	Soybean seed						
0	36.1	35.0	33.8	34.5	33.8	34.6	NS
45	33.4	33.5	34.5	34.3	35.2	34.2	NS
90	33.8	33.6	35.0	34.3	34.0	34.7	NS
135	35.0	34.1	32.8	34.0	34.2	34.0	NS
180	34.0	36.1	34.8	33.7	34.8	34.7	NS
Avg.	34.5	34.4	34.2	34.2	34.4		
FPLSD	NS	NS	NS	NS	NS		

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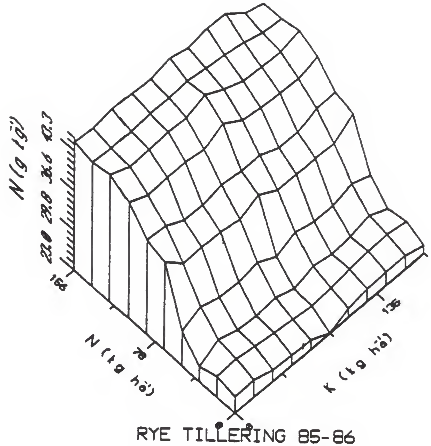
[a] Fisher Protected Least Significant Difference Test (P. <0.05), NS = not significant (P. >0.05).



RYE TILLERING 85-86

Fig. 7-4. Nitrogen concentration (g kg^{-1}) in rye and soybean plants affected by applied N and K fertilizer (kg ha^{-1}).

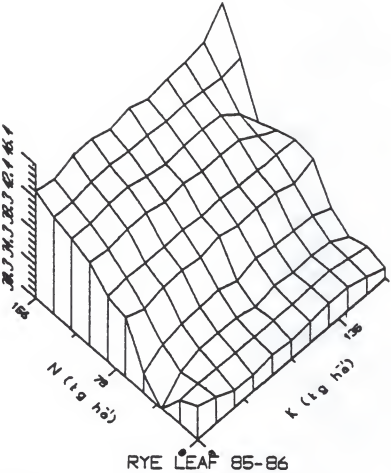
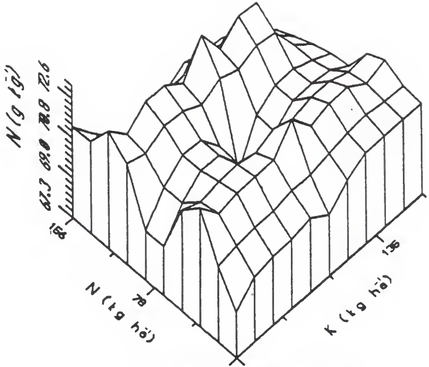
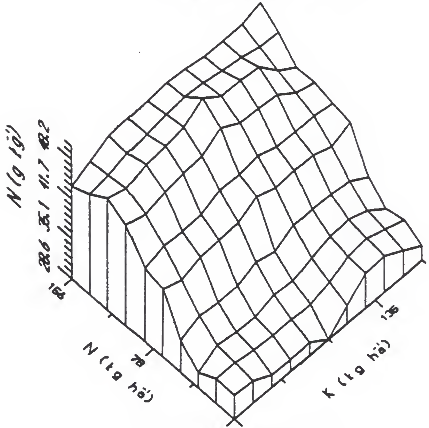


Fig. 7-4--continued.



SOYBEAN SEED 85-86



RYE LEAF RESIDUAL

Fig. 7-4--continued.

Table 7-7. Regression coefficients for equations predicting K concentration in rye and soybean plants.

Cropping Cycle	Intercept	N linear	K linear	N quadratic	NXK	R^2
	---------------------g K kg^{-1}					
	Rye tillers					
85-86	19.17	NS	2.00E-02	NS	2.03E-04	0.48
Residual	12.40	NS	1.70E-02	NS	NS	0.24
	Rye flag leaf					
85-86	13.86	-4.63E-02	1.37E-02	NS	NS	0.42
Residual	20.43	-9.34E-02	NS	NS	NS	0.47
	Rye grain					
85-86	5.35	NS	NS	NS	-2.53E-05	0.12
Residual	NS	NS	NS	NS	NS	NS
	Soybean leaf					
85-86	5.75	NS	1.71E-02	NS	NS	0.17
Residual	6.96	7.28E-02	3.82E-02	-3.13E-04	-2.67E-04	0.28
	Soybean seed					
85-86	NS	NS	NS	NS	NS	NS
Residual	16.88	1.02E-01	-1.98E-02	-8.00E-04	NS	0.28

NS = not significant (P. >0.05).

but did not respond to K during the residual CC. A NxK interaction was observed for rye grain in the 85-86 CC.

Soybean leaf showed a linear response to N in the 85-86 CC, then a curvilinear response to N, a linear response to K, and a NxK interaction during the R CC. Soybean seed in the R CC responded negatively to both N and K fertilization (Table 7-7).

Plant K

Nitrogen X K interactions were observed for the 85-86 CC rye tillers and rye grain, and for the residual CC soybean leaf and soybean seed (F-test, $P<0.05$) (Tables 7-8 and 7-9, Fig. 7-5). Extractable K increased as fertilizer K rates increased for rye plants at tillering stage. Less K was found at the 0 kg K ha^{-1} and 39 kg N ha^{-1} rates of fertilizer. Little interaction effect was shown by the rye grain. Higher extractable K was observed when 180 kg K ha^{-1} were applied and N was not added. Beaton and Sekhon (1985) reported that K content in wheat plants declines during the 7 weeks between anthesis and final harvest. The authors reported that at maturity, only 50 to 60% of plant K may remain in the plant. Potassium in the grain only accounts for about 18 to 24% of the total in the aerial parts of the crop. Because of the similarities between wheat and rye we can assume that an analogous behavior occurs in the rye plant. Therefore, most of the K that was absorbed by the rye plant before midseason was returned to the soil through senescent root and aerial plant tissues and plant

Table 7-8. Long-term plant K, fertilizer N vs applied K interactions 85-86 cropping cycle.

K rate	Fertilizer N						
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
	g K kg^{-1}						
	Rye tillers						
0	22.2	15.4	18.7	17.0	17.4	18.1	5.3
45	20.4	18.5	19.3	23.2	22.9	20.9	5.3
90	20.7	20.7	23.6	25.2	25.7	23.2	5.3
135	22.0	22.5	24.7	25.5	25.4	24.0	5.3
180	22.8	22.3	25.1	26.7	25.4	24.5	5.3
Avg.	21.6	19.9	22.3	23.5	23.4		
FPLSD	5.3	5.3	5.3	5.3	5.3		
	Rye flag leaf						
0	15.0	12.0	10.2	10.3	11.2	11.7	NS
45	14.4	12.4	10.7	12.4	9.5	11.9	NS
90	16.0	13.5	12.7	12.5	12.0	13.3	NS
135	15.3	13.3	15.1	13.9	12.3	14.0	NS
180	16.6	14.1	15.5	15.6	13.6	15.1	NS
Avg.	15.5	13.0	12.8	12.9	11.7		
FPLSD	NS	NS	NS	NS	NS		
	Rye grain						
0	5.0	5.9	5.4	5.6	5.2	5.4	0.7
45	5.4	5.6	5.4	5.3	5.4	5.4	0.7
90	5.5	5.3	5.1	5.3	5.3	5.4	0.7
135	5.7	5.2	5.5	5.1	5.3	5.4	0.7
180	5.7	5.4	5.5	5.1	5.0	5.3	0.7
Avg.	5.5	5.5	5.5	5.3	5.2		
FPLSD	0.7	0.7	0.7	0.7	0.7		

Table 7-8--continued.

	N rate						
	---kg ha^{-1}---						
	0	39	78	117	156	Avg.	FPLSD[a]
K rate -kg ha^{-1}	---g K kg^{-1}---						
	Soybean leaf						
0	6.2	5.3	5.6	4.9	5.8	5.6	NS
45	6.7	6.6	6.0	8.1	6.8	6.8	NS
90	6.4	7.6	6.7	7.4	7.2	7.0	NS
135	8.0	9.1	6.9	7.6	7.0	7.7	NS
180	8.8	8.8	7.0	8.5	7.7	8.2	NS
Avg.	7.2	7.5	6.4	7.3	6.9		
FPLSD	NS	NS	NS	NS	NS		
	Soybean seed						
0	14.6	15.6	15.0	15.0	15.3	15.0	NS
45	14.6	15.0	14.3	15.0	15.6	14.9	NS
90	14.7	15.9	15.0	15.0	15.4	15.2	NS
135	15.8	15.2	15.0	15.8	16.1	15.5	NS
180	15.9	16.3	14.0	14.6	15.8	15.3	NS
Avg.	15.1	15.6	14.6	15.0	15.6		
FPLSD	NS	NS	NS	NS	NS		

---

[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$).

Table 7-9. Long-term plant K, fertilizer N vs applied K interactions for the residual cropping cycle.

K rate	Fertilizer N						
	kg ha^{-1}						
	0	39	78	117	156	Avg.	FPLSD[a]
	g K kg^{-1}						
	Rye tillers						
0	15.7	9.8	11.0	10.2	12.0	11.7	NS
45	14.6	11.6	11.7	16.6	12.3	13.4	NS
90	13.6	13.6	14.5	15.9	16.3	14.7	NS
135	15.3	15.3	16.9	18.3	14.4	16.0	NS
180	16.3	14.8	16.8	18.3	16.5	16.5	NS
Avg.	15.1	13.0	14.2	15.8	14.3		
FPLSD	NS	NS	NS	NS	NS		
	Rye flag leaf						
0	24.0	18.5	10.5	13.0	11.4	15.5	NS
45	18.8	18.4	11.9	15.2	11.4	15.1	NS
90	19.1	19.1	15.1	14.6	13.4	16.3	NS
135	19.5	20.9	15.8	15.9	13.9	17.2	NS
180	23.5	19.3	15.9	19.3	12.1	18.0	NS
Avg.	21.0	19.2	13.8	15.6	12.5		
FPLSD	NS	NS	NS	NS	NS		
	Rye grain						
0	4.4	4.5	4.6	4.4	4.7	4.5	NS
45	4.3	4.4	4.5	4.5	4.9	4.5	NS
90	4.3	4.7	4.5	4.4	4.6	4.5	NS
135	4.4	4.7	4.6	4.6	4.8	4.6	NS
180	4.4	4.5	4.7	4.5	4.5	4.6	NS
Avg.	4.3	4.5	4.6	4.5	4.7		
FPLSD	NS	NS	NS	NS	NS		

Table 7-9--continued.

K rate	Fertilizer N						
--kg ha^{-1}--							
	0	39	78	117	156	Avg.	FPLSD[a]
	--g K kg^{-1}--						
	Soybean leaf						
0	7.9	9.6	11.1	9.8	10.8	9.8	4.9
45	7.7	11.0	10.2	12.8	10.8	10.5	4.9
90	7.8	13.8	11.8	12.3	10.7	11.3	4.9
135	13.0	14.3	13.0	12.3	9.5	12.4	4.9
180	14.3	14.5	11.5	13.5	10.3	12.8	4.9
Avg.	10.1	12.6	11.5	12.1	10.4		
FPLSD	4.9	4.9	4.9	4.9	4.9		
	Soybean seed						
0	13.9	17.0	21.3	16.4	14.0	16.5	6.4
45	15.9	22.7	18.8	16.0	13.3	17.3	6.4
90	16.9	21.7	21.9	14.3	14.1	17.8	6.4
135	14.4	18.5	24.0	14.6	14.4	17.2	6.4
180	12.1	14.2	15.4	15.3	14.9	14.4	6.4
Avg.	14.6	18.8	20.2	15.3	14.1		
FPLSD	6.4	6.4	6.4	6.4	6.4		

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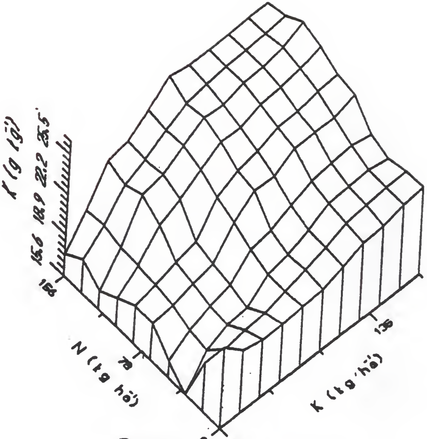
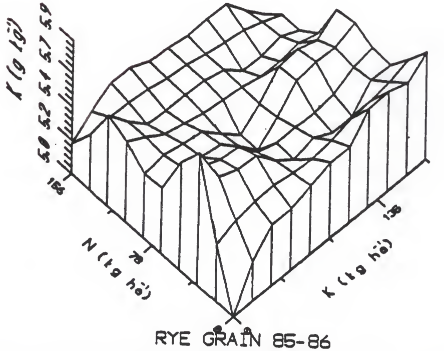
[a] Fisher Protected Least Significant Difference Test ($P < 0.05$), NS = not significant ($P > 0.05$).

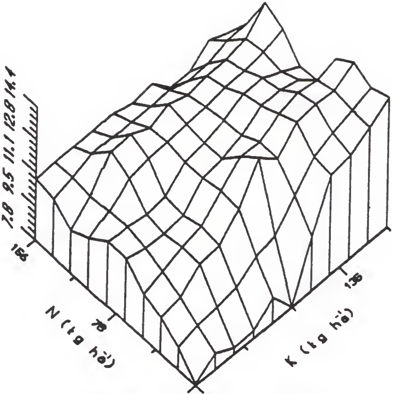


RYE TILLERING 85-86

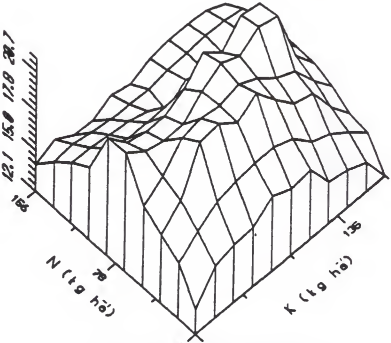


RYE GRAIN 85-86

Fig. 7-5. Potassium concentration (g kg^{-1}) in rye and soybean plants affected by applied N and K fertilizer (kg ha^{-1}).



SOYBEAN LEAF RESIDUAL



SOYBEAN SEED RESIDUAL

Fig. 7-5--continued.

decomposition before harvest. This K would likely be concentrated in the top 10 cm of soil because most small grain roots are found in this soil layer (Bruniard and Gallaher, 1988). Thus, more K became available for future uptake by the following soybean crop.

Extractable K increased as N rates of fertilizer increased for the soybean leaf. However, greater concentration of leaf K was observed when no N was applied or was applied at the 39 kg ha^{-1} rate with the highest rates of K (135 and 180 kg K $ha^{-}1$). Highest extractable K in the soybean seed was observed at the 78 kg ha^{-1} and the 135 kg ha^{-1} rates of N and K fertilizer, respectively. Higher rates of N or K fertilizer decreased K in the soybean seed. Hanway and Johnson (1985) stated that K uptake and accumulation by soybean occurs throughout the growing season. The rate of K uptake decreases during the seed-filling period and K translocation from the vegetative plant parts to the grain takes place. As a result, most K would not return from the soybean crop to the soil as it would by the rye crop. Therefore, lower extractable K in the soil surface was observed following the soybean crop as compared with the rye crop. The reverse effect was found immediately following the rye crops.

Conclusions

In a NT rye-soybean system, applying N annually to the rye crops but applying K only to the first crop produced good rye and soybean responses over two cropping cycles. Soil and plant nutrient contents help explain why. Higher soil N concentrations were observed following the soybean crops. This indicated that N was recycled to the soil surface from plant residue decay immediately after the soybean growing season. The opposite effect was found for the rye crops when interactions between K and sampling times were observed. Little K was removed by harvested rye grain. Most of the K absorbed by the rye crop was returned to the soil during seed filling and from plant decomposition before harvest. This residual K was then available for the rye and soybean crops during the residual CC.

The application of N fertilizer not only induced the plant uptake of fertilizer N but also had a synergistic effect by increasing native soil N uptake. A recycling of N and K from lower to upper depths was observed in this rye-soybean DC system under these NT conditions.

Nitrogen X K interactions occurred in different rye and soybean plant parts during both the 85-86 and the residual CC. In general, rye showed a greater response to N fertilizer and soybean better responded to K fertilizer.

Nitrogen and K nutrients were recycled by both crops to soil in this long-term rye-soybean DC system. These results agreed with the hypothesis proposed by Post (1983).

CHAPTER 8

GENERAL CONCLUSIONS

Fertilizer had a positive effect on rye (Secale cereale L.) whole plant dry matter (WPDM), rye grain yields (GY1 and GY2), rye percent ground cover (PGC), head weight (HW), percent grain head^{-1} (PGH), head area index (HAI), and soybean [Glycine max (L.) Merr.] seed yield (SY) in this no-tillage (NT) double-cropping (DC) system. Soybean seed yield responded positively to residual K applied to the rye crop. Thus, if K was applied to satisfy the needs of the rye crop, no additional K was needed for the soybean crop. These results agreed with those suggested by Gallaher (1977a) who felt that fertilizer applied to one crop may leave enough residual nutrients for a succeeding crop, thereby reducing costs to the total multiple-cropping system. A rye-soybean NT DC system will require different management as compared with the monocrop system of either rye or soybean.

Researchers should place more emphasis on developing fertilization programs which take into account nutrient cycling and residual effects of fertilizers. A rye-soybean NT DC system efficiently recycles nutrients when repeatedly practiced in the same soil. However, more research is needed to estimate the magnitude of nutrient losses. Fertilizer extension recommendations should be made to alleviate these losses without applying surplus fertilizer which may not be utilized by the crops under these conditions.

Application of P was not necessary to obtain greater net returns of rye WPDM, GY, and SY. Application of K to the soybean crop did not increase dollar net returns. Sufficient potassium can be applied to the rye crop in order to satisfy the needs of both rye and soybean. However, nitrogen is needed by the rye crop every time it is grown in this sandy soil. Phosphorus was not needed when greater N and K fertilizer rates as compared with the extension fertilizer rates were applied.

An interaction between fertilizer N and sampling time was observed. Higher N concentrations were observed after the soybean crops. This indicated that N was recycled to the soil surface from plant residue decay and decomposition immediately after the soybean growing season. The opposite effect was found after the rye crops when interactions between K and sampling times were observed. Higher K was observed after the rye crops. Little K was removed by harvested rye grain. Most of the K absorbed by the rye crop was returned to the soil during seed filling and from plant decomposition before harvest. This residual K was further used by the rye and soybean crops during the residual cropping cycle (CC).

The application of N fertilizer not only induced the plant uptake of fertilizer N but also had a synergistic effect by increasing native soil N uptake. A recycling of N and K from lower to upper depths was observed in this rye-soybean DC system under these NT conditions.

Fertilizer N X K interactions were obtained in different rye and soybean plant parts during both the 85-86 and the residual CC. In general, rye showed a greater response to N fertilizer and soybean better responded to K fertilizer. Nitrogen and K nutrients were recycled from crops to soil. These results agreed to the hypothesis proposed by Post (1983). Researchers should consider the agro-ecological factors involved in DC practices in order to make appropriate and economical recommendations for NT DC of rye and soybean.

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BIOGRAPHICAL SKETCH

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From 1981 to 1982 he worked as a research assistant at the Centro de Investigaciones Agronómicas, University of Costa Rica. In 1982, he worked for the Universidad Estatal a Distancia (UNED) in San José, and in 1983 he became a faculty member at the Centro Regional del Atlántico, University of Costa Rica, in Turrialba, Costa Rica.

He is married to the former Olivieth Maria Villalobos Villalobos and has a son Rubén Alberto Jr. and a daughter Natalie.

I certify that I have read this study and that in my opinion it conforms to the acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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